THE STUDY OF THE SOIL IN THE FIELD

BY

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PREFACE TO THIRD EDITION

THE production of a new edition to include recent ideas on this subject is in the present circumstances too difficult to undertake, but a compromise has been reached, by adding the text of the author's new Official Handbook and Field Soil Description Sheet of the Soil Survey of England and Wales in the form of an appendix to the existing second edition. This new appendix is completely technical and assumes that the reader is already familiar with soil work in the field and has grasped the main principles of soil profile study as explained in the main portion of the book.

1941. G. R. C.

PREFACE TO SECOND EDITION

The first edition of this little work was so kindly received by soil workers in many parts of the world, and their criticisms were so encouraging, that I have endeavoured in this second edition to embody as many as possible of their suggestions for its improvement. The main theme has been changed but little —certain small changes and amplifications have been made to clarify obscure points, but the chief alteration lies in the addition of certain entirely new material. I have tried to improve the section dealing with soil structure by evolving a new system of nomenclature. I have been able to add some advice on the use of simple topographic instruments for 'running lines', obtaining 'slope data', &c., for ground survey in preliminary reconnaissance. Additional information on methods of sampling other than by monolith is given, and some useful tools are described. The English method of 'series mapping' has been written up in sufficient detail to allow the reader readily to interpret English soil maps and memoirs. I have also been privileged to include the details of Osmond's method for the classification of soil colours in the field. I sincerely hope that my friends will recognize the skeletons of their suggestions in the new text and will continue to give me their valued criticisms and help.

G. R. C.

PREFACE TO FIRST EDITION

By C. G. T. MORISON, M.A.

Reader in Soil Science in the University of Oxford

SOIL science as it is understood to-day is a complex study involving many branches of fundamental science, and the problems presented for solution are such as can perhaps only be solved satisfactorily by a team consisting of physicists, chemists, geologists, botanists, and zoologists.

There is, however, one aspect of soil study which was for many years sadly neglected, but which is of fundamental importance not merely in the problems of classification but also in elucidation of many of the problems of land utilization.

The study of the soil in the field makes demands upon the worker of a somewhat peculiar nature: it requires not merely a knowledge of natural science of no mean order, but it demands a faculty for keen and accurate observation of details which are by no means easy of observation, and which may easily escape the notice of any but the most practised eye.

Mr. Clarke, helped much by his sympathetic feeling for this aspect of soil work, has made it his special study, and has endeavoured in this book to put together his own experience and that of other workers in the same field in such a way as to be of assistance to students and others. There are many people overseas both in Government employ in the Agricultural, Forestry, and other services, and those engaged in the various planting industries, who are

not and never can be soil specialists, but to whom some knowledge of the soil is essential, and to whom some instruction as to what to look for and to describe and record is of very great importance.

Only if observations of this kind are to some extent codified, do they become exchangeable between one person and another.

It is hoped that this book may prove useful to soil scientists in general, and in particular to those to whose lot it falls to carry out observations in the field in one of the most fascinating and complicated of natural phenomena.

ACKNOWLEDGEMENTS

THE writer wishes primarily to express his thanks to C. G. T. Morison (University Reader in Soil Science, Oxford) for all his kind help, guidance, and friendship during the past twenty-five years. To A. Muir, G. Milne, R. Bourne, A. H. Lloyd, G. V. Jacks, M. O. Tandy, J. Dougan, D. A. Osmond, W. Morley Davies, T. Wallace, and to all those other gentlemen from whose notes or papers the writer has been enabled to obtain a clearer insight into many new aspects of the subject.

Finally, the writer is indebted to those numerous friends both at home and abroad who, when on leave or when occasion allows, just 'drop in' to discuss their work and in consequence give him so much valuable information.

CONTENTS

INTRODUCTION

THE study of the soil in the field comprises the detailed and accurate observation of certain natural phenomena, including not only the growth and development of surface material but the soil as a whole in relation to the various forms of life with which it is associated. The study in the laboratory of the material obtained by the sampling of a soil pit is an essential adjunct to soil study, but it is not the study of the 'living soil'. So soon as a soil sample is removed from its environment it 'dies', and though laboratory investigation is necessary in order to obtain information not otherwise available it is essentially of the nature of a post-mortem examination. Soil scientists are now beginning to realize that the story of a soil is told by an examination of it in its natural environment. The observations of the land worker have been used by him in the utilization of the soil from the earliest ages, but these very observations which have meant so much to him have too frequently been neglected or discounted by the laboratory investigators of the last half-century. The idea that a simple chemical analysis of a 'dead' soil sample taken in any arbitrary manner would solve the problems of economical fertilizing and cultivation is now fortunately nearly extinct. In its place is growing the conception of the soil as a live substance, almost an entity. A soil grows, develops, and responds to environment, care, and sympathetic treatment much as a true organism does, and history is full of examples of man and soil working together towards their mutual evolution, and, in fact, the

farther one goes back into the history of the agricultural utilization of land the more one is led to believe in this definite but indefinable property of land and soil. Like other organisms, a soil possesses special characteristics by means of which it can be recognized and, in consequence, ultimately classified. The term now generally adopted to describe the 'form' of the soil is 'soil profile'. The soil profile is the manifestation of all the changes, growth, and development which have taken place during the 'life' of the soil, and it may be studied by any intelligent observer when he works on the land or digs a hole in the earth. The pedologist must be a naturalist in sympathy with his subject, must know what to look for, and how to interpret the true significance of his observations and utilize them for the advancement of his study. The background of the pedologist's stock-in-trade is a general knowledge of chemistry, geology, and botany. The necessity for systematic study of the soil profile, both in relation to its environment in the field and its behaviour in the laboratory, becomes evident after the consideration of a few points.

Since, until a subject of study is classified, knowledge of that subject is incomplete, it is obvious that the first and fundamental duty of pedologists is the classification of soils. Many efforts have been made to standardize a system of soil classification, nearly all of the more recent of which have been tolerably successful in the countries of their origin, and soil utilization schemes and maps have resulted. They all differ, however, in their systematism and nomenclature one from another, but they all recognize the necessity for

the profile pit as the picture of the life-history of the soil. For the rational utilization of land, to which end all pedological researches should ultimately be directed, a soil-profile survey is essential. In recent years much field work has been carried out by soil mapping on a texture basis, and valuable though this may be in the recognition and classification of localities of sands, loams, and clays, there is still a large gap between the information required and the information obtained. The field-man during the making of a good texture-map obviously does a great deal of profile observation in a general way, but he rarely makes a systematic study of the genesis of the soil or attempts to correlate it with its natural vegetation. A texture survey, in short, is merely one item in the more comprehensive study of the 'soil site' and 'soil profile'. A good soil description on the 'site and profile' principle should be so complete that no further information is required to arrive at a technically perfect system of rational utilization. The ideal for which the pedologist must strive is the accumulation of knowledge for the ultimate utilization of land, and no system of soil study has yet been evolved which can supply this knowledge better than the study of the soil profile in relation to its environment, first in the field and then in the laboratory. In the soil environment must be included the natural or cultivated vegetation, since, until the weathering complex of the mineral material has borne vegetation and obtained its complement of humus and become 'live', the material is not soil. The term 'humus' in the foregoing sentence includes not only the products of the decomposition of

vegetable matter but also the living organisms which bring about the biochemical reactions of this decomposition. Newly weathered rocks, desert sands, or sea sands, until anchored by vegetation and humus, cannot be soils or develop into soils. Vegetation and soil development cannot be dissociated, since it is impossible to see or to find out where, in the soil proper, vegetation ceases and the ultimate mineral particles of the soil begin—they are, in fact, completely merged into a natural living unit.

Dr. C. F. Marbut, whose death deprived soil science of one of its most outstanding personalities, in his instructions to his field surveyors in America, made the following remarks:

'The soil is a natural body, developed by natural forces acting through natural processes on natural materials. Its true nature cannot be determined except through a study of the natural or virgin soil. Any effort to arrive at a complete understanding of the soil by studying it only or mainly as it has been modified by man in cultivated fields will involve necessarily a great loss of time and the danger if not almost the certainty of committing gross errors. It is almost as reasonable and practicable to study the soil in cultivated fields alone or mainly, and expect fundamental results from such studies, as it would be to study the botany of the world's vegetation by devoting attention to cultivated plants only. The botanist does not pretend, nor does any one urge that he attempt, to study his subject by studying cultivated plants mainly, yet in much of our work in the past the cultivated soil is the soil that has been examined, sampled, and described.'

I

SOIL-SITE CHARACTERISTICS

MAN in his endeavour to make use of the soil for his needs was compelled to adopt certain methods for the recognition of what he required. When he found that all his requirements could be assessed in one unit of land, he adopted what he considered to be a sound system of utilization. The system was not always strictly according to the rules of natural site selection because he had other factors with which to contend, such as conditions of land tenure, availability of site for economic development, &c., but from the place-names of old settlements or from archaeological excavations one is compelled to believe that early man had a very shrewd idea of the best land units for his simple needs, e.g. well-drained, calcareous soils with clear water-supply.

A unit of land suitable for a single system of utilization may be termed a 'site'. Man has always recognized 'site', but has not always realized how he has arrived at his conclusions. In the selection of his soil site for his needs, he consciously or otherwise assesses the value of his unit from a consideration of the same general characteristics as were observed by Dokuchaiev towards the end of the last century during his attempted soil-utilization survey of Russia.[1] He observed that every 'dry land vegetative soil' is a result of the functioning of the following factors:

i. The climate of the locality.

[1] J. N. Afanasiev, *The Classification Problem in Russian Soil Science*, Moscow, 1927.

ii. The nature of the parent material.
iii. The mass and character of the vegetation.
iv. The age of the country.
v. The relief of the locality.

He then concluded that when all the above factors were similar in two different localities, no matter how far apart, the soils would be similar. That is, they have a similar life history and are pedogenetically related; or, in still another way, if the soil sites of two different localities are similar the soils are similar. These conclusions lead on to the natural corollary that if all the soil-forming factors or site characteristics are known, then the soil-profile characteristics may be foretold. Though Dokuchaiev's observations and conclusions have been the foundation of all subsequent soil-profile study in the field, and the backbone of the science of pedology, it is unfortunately not quite all the story. Certain other factors have also to be considered in view of modern economic demands, especially with reference to man's interference and management of natural sites, either for his needs in the past or in the immediate or distant future.

Assuming that Dokuchaiev's general items for observation are the minimum possible for the assessment of the soil site, it is necessary briefly to discuss the part played by each factor in the production of the complete whole. Table I illustrates the Oxford Soil Science Laboratory method for the description of the soil site and its soil-profile characteristics. It is not suggested that this necessarily represents a complete schedule of observations, but it has been used with some degree of success in field investigations in many

TABLE I

SOIL SCIENCE LABORATORY, OXFORD

A. World Group. *Index No*..............................
B. Variety (Soil Series). *Date* ....

Site Characteristics

I. Locality of Site.
II. Age of Site.
III. Parent Material and Mode of Formation.
IV. Topography (Aspect, Slope, Altitude).
V. Drainage (Maturity).
VI. Climate (Rainfall, Wet and Dry periods, Temperature data, Prevailing wind, &c.).
VII. Vegetation (Plant Formation—Plant Association).
VIII. Human Influence.

Scale sketch of local relief

Profile Description

Each horizon to be described in the following order:

(1) Horizon Name.
(2) Depth and Clarity of Horizon.
(3) Colour (of Smear; and of soil mass *in situ*)
(4) Carbonates or none. (Nature of material, concretionary or relic).
(5) Texture (Sand, Loam, Clay, &c.).
(6) Organic Matter (Form of and disposal).
(7) Structure (Size and shape of aggregates).
(8) Consistence, Constitution (Compactness, porosity, tenacity, &c.).
(9) Mineral Skeleton (Nature of and proportion of stones).
(10) Special Characteristics:
Degree of moisture.
New chemical deposits.
Acidity as pH.
Drainage characteristics.
Root penetration and effects of fauna.

different countries. The items to be described are set out in the form of a questionnaire on the left-hand side of a double sheet of foolscap. A scale diagram of the profile may be drawn in true colours by means of smears of soil and the answers to the questionnaire written in on the blank right-hand side. The writer has found by experience that unless a site and its profile are recorded in a definite order, many points are invariably missed. The reverse side of the questionnaire is reserved for laboratory data, the minima of which are given in Table I*a*.

THE SOIL SITE AND PROFILE DESCRIPTION

Discussion of Items.

Items A and B. World Group. Soil Variety. Soil Series, &c.

These two items are placed at the top of the soil-description sheet for indexing purposes, though it is obvious that they cannot be filled in until all the other items have been assessed and classified. The names used in the descriptions for World Groups are mainly those based upon their climatic distribution, and are capable of translation into any other terms demanded by any particular system of classification. For example, the Podsolic soils of the Russians find their counterpart in certain of the Pedalfers of Marbut, while the Chernozem corresponds quite satisfactorily with certain of the Pedocals of America or with certain of the Black Soils of Africa.

The Soil Variety has a much more local application

TABLE I*a*

SOIL NO. ANALYTICAL DATA

Horizon Name	1	2	3	4	5	
Loss on Ignition						
Moisture						

MECHANICAL ANALYSIS EXPRESSED AS PER CENT. OF MINERAL MATERIAL

Coarse Sand						
Fine Sand						
Silt						
Clay						

CLAY ANALYSIS

SiO_2 Per cent.						
SiO_2 mols						
Al_2O_3 Per cent.						
Al_2O_3 mols						
Fe_2O_3 Per cent.						
Fe_2O_3 mols						
$\frac{SiO_2}{Al_2O_3}$ mols						
$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ mols						

ORGANIC ANALYSIS

C per cent.						
N per cent.						
$\frac{C}{N}$						

ROUTINE DATA

$CaCO_3$ per cent.						
Exchangeable Ca						
pH						

REMARKS

4488

B

and is capable of a very free translation. It may be used merely, as in the Russian manner, to denote a loamy or clayey variety of the World Group Podsol, or in the English-speaking countries it can be made to include both Series and Type.

Some systems of soil classification and soil mapping are outlined later.

SOIL-SITE CHARACTERISTICS

Item I. Locality of Site (Region or Catena) Lat. and Long.

In a country for which adequate maps are available the delineation of the boundaries of the region and its representative site can be determined comparatively easily. For the identification on the map of large areas such as Soil Regions or Soil Provinces the degrees and minutes of latitude and longitude will usually be sufficient. For example, from an examination of a map, the main watersheds and catchment areas stand out as simple, natural, topographical regions and, if a place name be given in conjunction with the latitude and longitude, the locality is clearly defined. Since, however, a soil site may be dependent upon a set of peculiarly local conditions, such as may occur in one of the recurring units of a catena, it will be found necessary in most cases to state the name and edition of the map, its representative fraction and, if possible, the exact position to a yard by cross-squaring. In countries such as England, where a rapid sequence of different geological materials outcrop, and where the climatic influences are comparatively uniform, a

sequence of soil profiles may develop. Each soil profile is representative of a certain soil site, and the association of a sequence of such sites in any area will constitute a Soil Region. The Soil Region is discussed in great detail by R. Bourne.[1]

The term 'catena' has been used by G. Milne[2] to

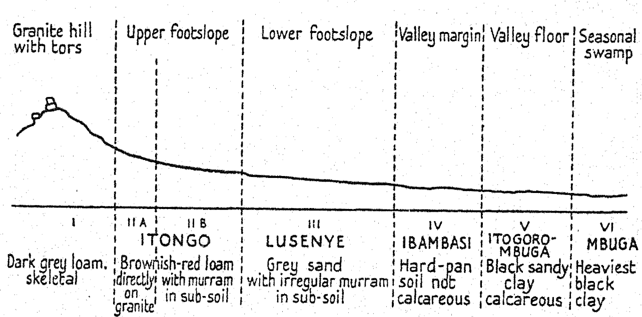


FIG. 1.

express a sequence of soil profiles which appear in a regular repetition in association with a region possessing a regular succession of certain topographical features. A common example of a catena occurs in the regularly undulating lands of the tropics, where the soils on the ridges may be red loams, with murram (iron concretion) soils on the lower slopes and black soils in the bottoms, or valleys.

Fig. 1 represents such a sequence recently recorded

[1] [*Regional Survey*. R. Bourne. Oxford Forest Memoir No. 13.]

[2] 'Composite Units for the mapping of complex soil associations.' G. Milne, *Trans. 3rd Internat. Cong. of Soil Science*, vol. i.

by Milne during a reconnaissance survey in Tanganyika.[1] The accompanying text explains the general principles upon which his catenary definition is assessed.

At Ukiriguru (and the pattern is repeated throughout its neighbourhood) the soil complex is a good example of the catena or topographic sequence of types, the zones running in succession from the flanks of the rocky hills to the lowest parts of the intervening valleys. The sequence is as follows.

I. Hill-tops and rocky parts of slopes: scanty skeletal grey loam in crevices of rocks. Vegetation probably originally 'miombo,' for a specimen of *Isoberlinia globiflora* was seen, but there is nothing now but a light growth of secondary bush.

II. Zone at foot of rocks, 100 to 300 yards wide across the line of greatest slope, but may be locally more extensive, as on slopes of larger hills or saddles between them. Coarsely gritty brown to red-brown loam ('itongo') of variable depth, based directly on the granite in the upper part of the zone but having a hard clinker-like 'murram' horizon at 1½ metres depth lower down the slope. The whole profile is slightly acid. Only remnants of the woody vegetation remain, including *Afzelia quanzensis*, *Tamarindus indica*, *Dalbergia melanoxylon*, *Kigelia*, and *Terminalia* and *Commiphora* species.

III. Next zone below, where the slope is perhaps 1 in 50: Very sandy pale grey 'lusenye', acid in re-

[1] G. Milne, 'A Soil Reconnaissance Journey of Tanganyika Territory', *East African Agric. Res. Stat. Report*, Amani, 1936.

action, of variable depth, sometimes based on the underlying bouldery granite, sometimes with a coarse grey-black-yellow sandy 'murram' as an intervening horizon. The one feature or the other seems to depend on whether the underlying rock is sufficiently rotted to be porous, or is impervious. The grey colour is due to the high wet-season water-table. Natural vegetation not seen, chief crop in cultivation is cassava.

IV. Next zone below, approaching the floor of the valley: dark brownish-grey gritty clay with 'hard-pan' profile, termed 'itogoro-ibambasi'. Seen after heavy rain, this soil was saturated in the top 40 cm., but quite dry below; water seeped out copiously at the depth named when a pit was dug into the dry subsoil. At 1 metre depth the subsoil is a dry gritty grey-yellow clay, not calcareous; the whole profile is acid, much more so in the top 60 cm. than below that depth. Original vegetation not seen, cultivation to grain crops.

V. On the valley floor, but not quite the lowest part: Heavy inky-black sandy clay, wet to the full depth of a 1½-metre pit at the time of sampling, and showing no hard-pan horizon. This clay does not seem to crack much in dry condition; seen wet, there were no visible structure lines. Calcium carbonate occurs at all depths, in the form of particles which are so numerous from 120 cm. downwards that they give a whitish cast to the colour of the subsoil. There is no definite nodular horizon, but the white particles include some of a large concretionary habit below

120 cm. This soil is given the name 'itogoro-mbuga', and on the Ukiriguru farm was being planted with ground-nuts (20 Jan.). Ordinarily such land is grazed only, or planted to sorghums.

VI. In swampy reaches of the valleys there are local areas of the heaviest black cracking clay, known as 'mbuga ya bugado', carrying stands of *Acacia seyal*.

Such a sequence of soils would appear over and over again in consecutive undulations of the land in the particular topographical region when traversing at right angles to the feature, but the profiles encountered in parallel with the feature would be uniform. A similar difficulty is presented in mapping the soils of the South-Eastern Steppes of Russia, where the 'motley' soils described by Kostychev occur. In this region five-metre strips of chernozem alternate with similar strips of saline soils. When under the influence of natural vegetation, the chernozem is in association with the typical Steppe feather grasses (*Stipa stenophylla* and *S. capillata*) whereas the grey steppe is associated with *Artemisia maritima*. When the whole catena is ploughed and put into wheat, the crop grows to the height of 1 metre and is of good quality on the chernozem, whereas that on the grey saline soils only grows to about 25 cm. and then turns yellow and withers.[1]

To map such soils a 'Series' or similar system could only be applied to typical sites in the centre of

[1] In such problems it appears that the micro relief is of great importance. Sokolovsky, *Problems of Soil Structure*, Moscow, 1933.

each area, because the rapid merging of the one into the other in a direction at right angles to the features would preclude the delineation of any sure boundaries. The catena therefore is a very valuable addition to our soil vocabulary and designates a very important unit in soil mapping.

Item II. Age of Site.

This item is of importance in assessing the degree of maturity of the soil produced under the present régime of soil-forming factors. It is the soil in equilibrium with its present environment which must be described, and all archaic influences, unless still producing effects, must be discounted. For example, it would be incorrect to describe a soil as a Brown Forest Soil if the original deciduous forest had been cut and cleared so long ago as to have allowed the soil to become degraded in humus content, despite the fact that it would revert to forest and become regraded in quite a short time if left to natural influences. Age of site is closely related to topography and can briefly be described as being either mature or immature. It must be remembered, however, that changes are always in progress, and it is essential to determine whether the soil-site is the result of old and practically stable conditions (residual soils) or is the result of some more recent geological or pedological process. The following hypothetical chain of events in soil evolution is somewhat improbable, because of side issues and the influence of certain other factors, but is made to emphasize the importance of a time factor upon soil life-history.

Imagine a vast tract of new land of variable topography, and with a variety of geological formations outcropping under a cool humid climate with an evenly distributed rainfall, say, about 1,500 mm. per annum, a mean summer temperature of about 20° C., and a mean winter temperature of about 8°–10° C. If the rocks are at all permeable and are weathered down to a detritus on which some vegetative growth is possible, it will follow in course of time that soils will develop. Under these climatic conditions, the percolation of rain-water will tend to exceed the surface evaporation, except in those cases where surface run-off is so great as to cause direct erosion. A steady washing out naturally ensues from the surface horizon of the finer mineral particles and also of those materials soluble in water, carbon dioxide water and organic acid water produced by the decomposition of the vegetable matter. A time will come, therefore, when the surface material or soil has become almost destitute of all mineral material except quartz, while the underlying material must become proportionally richer in some of these substances. These will tend to be thrown out of solution as insoluble substances due to electrochemical, biochemical, or other processes, and hence to accumulate. On fairly flat topography this precipitation and accumulation may continue until further percolation is impossible, and the water must either escape by lateral drainage or bog conditions will prevail. (Such cases do in fact occur on Dartmoor, where a secondary 'swamp soil' is built up upon the accumulation zone of an archaic podsol. The anaerobic condition so produced, however, re-

duces the reddish iron compounds and the horizon becomes so much lighter in colour as to give the impression of a reduction or remobilization of the iron compounds.) During the evolution of this soil type each hiatus in its formation is accompanied by its specific vegetational climax, some of which tend to prevent, while others tend to foster, soil movement or 'creep'. The end of the one cycle comes when the loose material of the surface horizon of the upland site has slipped down into the valley and left the accumulation zone exposed to further aerobic weathering. (Such truncated soils are quite common in various parts of the world.) Another vegetational climax becomes established and weathering proceeds, while wind, erosion, and creep continue to remove the loose unanchored products towards the lower sites. (The outwash of soil from uprooted trees is quite appreciable on hill-side sites.)

Thus by the cumulative effects of environmental conditions, including the soil-forming processes, the topography of the land becomes changed with the tendency towards the elimination of irregularities and to the formation of smooth curves. Such changes in main topography will be followed by changes in climate, followed by changes in vegetational climaxes and in soil site. The climate will progressively become drier, winds will be stronger, and surface evaporation will increase. Such conditions will produce a more and more xerophytic type of vegetation which will, in time, tend to produce steppe or even desert. The large-scale clearing of prairie for arable use in Canada and the U.S.A. by the removal of cover without

compensating shelter belting is already causing widespread distress by the loss of the entire surface soil. It may be due to such processes that the great plains

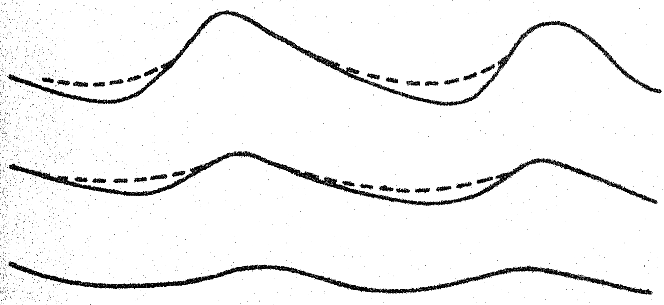
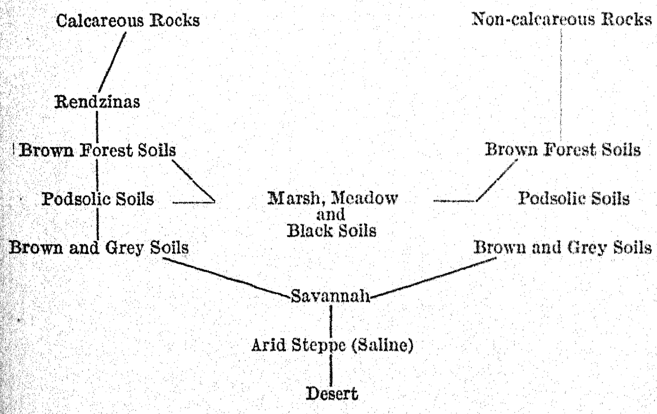


FIG. 2.



of the continents owe their development. See also p. 52.

Fig. 2 illustrates these hypotheses.

Fig. 3 represents an actual land-form described by P. Topham in Nyasaland.[1]

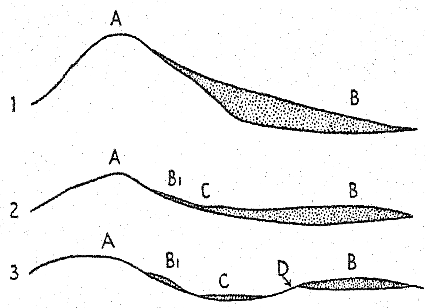


FIG. 3.

Common form of landscape structure.

The three diagrams represent stages in the weathering of a hill A. The shaded portion B is a quartz drift derived from A; B_1 is a small secondary drift. The main mass of B becomes separated from A by erosion of the drainage basin C.

At the present day, as depicted in diagram 3, B is a leached sandy hill top; at D there is an outcrop of *lubwe*, concretionary ironstone; B_1 is a drift soil but less leached than B; it is often fertile, normal erosion being rapid. B is infertile and carries *Uapaca* forest.

Item III. Nature of Parent Material.

A very real difficulty often presents itself to the fieldman in determining whether or not the soil material with which he is working is truly derived from the rock immediately beneath. The recognition of the soil-forming minerals in a well-developed or mature soil is by no means easy, and so it becomes necessary to discover the relationship between the soil and the true parent rock, the mineral composition of which is more readily discernible.

[1] Imperial Forestry Institute, Oxford, Paper No. 5.

The American Soil Bureau recognizes four groups of geological materials which come under the headings of Parent Material:

Igneous	*Sedimentary*	*Metamorphic*	*Unconsolidated*
Granite	Sandstones	Gneiss	Clays
Syenite	Shales	Schists	Sands
Diorite	Conglomerates	Slates	Gravels
Gabbro	Limestones	Quartzite	
Porphyry		Marble	
Felsite			
Basalt			
Obsidian			
Pitchstone			
Pumice			

The English Soil Survey, on the other hand, though using much the same general divisions, has dealt much more specifically with local geological outcrops, since under temperate maritime climatic conditions the nature of the parent material appears to be of primary importance in the classification of the Soil Series.[1]

A tentative list of the Parent Materials, recognized by the English Soil Survey Conference, with their respective symbols and colours used in mapping, is given below:

Group No.	*Parent material.*	*Symbol.*	*Colour on map.*
1	Acid Igneous Rocks	G	Crimson
2	Basic Igneous Rocks	B	Pale and purple-crimson
3	Ultra basic Igneous Rocks	Σ	Pink
4	Basic Tuffaceous Shale	Ts	Bluish-grey
5	Schist and Gneiss	m	Crimson
6	Slate and Hard Shale	b	Blue-greys
7	Clay and Clay Shales, Calcareous	g	Yellow-browns
8	Clay and Clay Shales, Non-calcareous	d	Grey-greens

[1] Soil Surveyors' Conference, Paper No. 38.

Group No.	*Parent material.*	*Symbol.*	*Colour on map.*
9	Red Clay, Calcareous	c	Yellow-browns and salmon-pinks
10	Red Clay, Non-calcareous	q	Yellow-browns and salmon-pinks
11	Silt-clay	ω	Yellows or ivory
12	Sand, Calcareous	y	Blue-greens
13	Sand, Non-calcareous	a	Brown-pinks
14	Sandstone, Calcareous	s	Blue-greens
15	Sandstone, Non-calcareous	f	Brown-pinks
16	Sandstone, Felspathic, Non-calcareous	t	Green
17	Glauconitic Sand	p	Emerald green
18	Hard Limestone	v	Prussian blue
19	Soft Limestone	r	Yellow and pale orange
20	Chalk	h	Olive green
21	Brickearth	-▭-	Yellow
22	Peat	-⌄-	Smoky yellow
23	Complex drifts:		
	a. Clay-with-flint	ç	Greenish yellow
	b. Red drifts	x	Slate grey
	c. Grey drifts	x	Slate grey

In addition to these materials as a direct basis for the Series classification allowance is also made for variation of material within the main group and a further delimitation is made by sub-grouping.

a. In group 1 of acid igneous rocks, a sub-group would include the *various* acid igneous rocks as granite, quartzose schist, &c., or acid igneous rock and hard shale as drift.

In Group 15 'Sandstone, non-calcareous', would include red or yellow sandstones and their drifts.

b. Factors in the development of the Series according to whether the soil is derived from a 'straight' (*in situ*) deposit or from its drift.

Use is also made of what is termed the 'Composite P.M. profile'. Such profiles are composed of thin washes of material over a group or sub-group material, but this term must not be confused with the *pedogenic* profile.

The presence or absence of drift material is of great importance, since, although the drift may not be derived from the rock beneath it, yet it is obviously the parent material of the soil. Deep drift or old drift can act as 'parent rock' in soil formation as readily as a true geological rock, and it is in these cases that a knowledge of the age of the site becomes of great importance.

In field work there are, however, many small details which will help the surveyor to gather a rough idea of the source of his material. In geologically surveyed country the geological map is of great assistance, but should not be too closely followed without giving full regard to the recent topography. The older types of geological map usually ignored just those depths of surface material which the soil man most requires. Large drift areas of old time may usually be recognized by their differences in colour and bedding, and in the chemical and physical nature of the transported stones and minerals. For instance, when a quantity of quartzose pebbles and sand is found mingled with the surface layers of sedentary soil on deep sea clay, it may be assumed that the soil could be described as 'sedentary clay modified by quartz drift'. This modified material in conjunction with topography may be of sufficient depth to become the dominating factor in the soil formation, in which case

it would then be described as 'deep quartzose (gravel) drift overlying sedentary clay'. Greater difficulty usually occurs, however, in dealing with the definition of 'local' drift. Local drift usually occurs as thin smears of differently constituted mineral mixtures distributed with varying degrees of intensity all over the topographical region, and may usually be recognized in the features of the mezzo-relief (see p. 35). The importance of the actual chemical nature of the parent material varies greatly with the type of soil under investigation. Mature soils, such as certain podsols and laterites, are generally presumed to have developed out of all chemical relationship to the original geological rock. In temperate climates, however, where Brown Forest Soils and Rendzinas occur, it appears to be chiefly the chemical nature of the parent material which determines to which group of soils the soil belongs.

Mode of Formation.

The mode of formation of the site is chiefly dependent upon the phenomena of land formation, mainly during geological time, but frequently during recent time, in such cases as landslide, erosion, or creep.

The surveyor must endeavour to determine from the general lie of the land and the nature of the geological material whether the soil site is the result of a sedentary or massive deposit weathered *in situ*, or whether it is of more recent origin. There are four main agents which are responsible for the laying down of the 'recent' parent material, as distinct from the *in situ* weathering:

(1) Ice	gives	Glacial Drift (Till and Boulder Clay, Moraines).
Ice	,,	Fluvio-glacial Deposits (Outwashes of gravels, &c.).
(2) Water	,,	Alluvium, Terraces, and Cumulose Deposits.
(3) Gravity	,,	Colluvial Soils or Creep Soils.
(4) Wind	,,	Brickearth, Loess, &c.

The clue to which of these groups the soil owes its formation is frequently to be found in the field from the size, shape, and colour of the sand grains or the stones, taken in conjunction with the topography and geological nature of the underlying rock.

(4) *Wind-borne* material is nearly always very fine and rounded, unstratified, and quite frequently in deep folds where wind force became reduced by obstruction, e.g. lee side of topographical features.

(3) *Gravity* or colluvial soils usually show themselves as an average of the components of the surrounding sites; stones and sand grains may be either coloured, angular, or round, but, unless they are rounded in the original rock mass, they do not usually travel far enough to undergo much change in taking up their new position.

(2) *Water.* Water deposits are probably by far the most numerous and variable, but it is fairly safe to assume that, after the elimination of wind and glaciation as possible factors, the dominance of rounded and rubbed sand grains signify one or other of the water deposits. In these cases knowledge of the age and nature of the topography is of great assistance.

(1) *Ice.* The effects of glacial or fluvio-glacial actions are usually very clearly defined by the topographical features. The lithological character of the pebbles is usually distinct from that of the underlying rock. They are usually sub-angular in shape and bear evidence either of considerable abrasion on one side or, if rounded off, give the impression of having once been rubbed more on one face than the other. They are rarely, if ever, so round as fluviatile deposits. Glacial stones, too, are, as a rule, very hard, though in the case of the Great Chalky Boulder Clay this is not so, because soft chalk pebbles are found in great quantity. The explanation of this may be that the chalk floated as a lateral moraine.

Item IV. Topography (Altitude, Aspect, and Slope).

It is difficult to analyse the relative importance of the various soil-forming factors, but undoubtedly topography is frequently the dominating influence controlling the local climate, vegetation, and regional drainage.

The general lie of the land or *main* topography strikes the observer directly he enters a region, and such outstanding features as the vertical zoning of vegetation on mountain sides, or flat plains with meandering streams, obviously lend themselves to the formation of characteristic soil sites. In general it is enough to classify the main topography into three main groups:

1. Upland sites.
2. Hill-side sites.
3. Lowland sites.

The distribution of these main groups in relation to each other will be found as follows:

Mountains.	*Upland Plateaux.*	*Main Escarpments.*	*Plains.*
Peak	Peak	Hill-sides	Ridges
Plateau	Plateau	Crest sites	Isolated hills in plains
Mountain-side	Valley Bottom	Escarpment shelves	Flat plains
Valley Bottom	Peneplain		Easy hill-sides
			Basin sites
			Riverain sites

In the temperate zone the soil characteristics of such sites will be entirely different, upland pasture being characterized by *Festuca Ovina* and lowland pasture by *Nardus* and *Deschampsia.* Such groups are dominated mainly by altitude and aspect. For instance, the soils on the northern and southern slopes of the Southern Alps differ very greatly, both in colour and profile.

On the great Loessial plateaux of China which have been deeply dissected by rivers, the topography consists of steep hills with flat tops between deep and narrow valleys. The hill-sides facing south are subjected to intense drying out after the rains, whereas the northern slopes are cooler and more humid and allow of a luxuriant growth of vegetation. Because of this the soils on the north hill-sides are dark and humic, while those on the south slopes are chestnut-coloured and less fertile.

Again, the climate towards the summit of even a one-thousand metre mountain varies sufficiently from that in the valley to produce quite a different natural vegetation and soil type. In the soil description, therefore, the first remarks on topography must

classify the soil site according to the three main groups.

Such groups, however, are generally capable of a further division dependent on what may be termed *Mezzo-relief*. Mezzo-relief includes those smaller topographic features which come to the notice of the observer in a second glance, such as the gentle undulations of a plateau, the slope of a peneplain, or the dip and escarpment slopes of small geological outcrops. The soils formed on such sites will be dependent to a greater extent upon slope than upon variations in altitude and aspect, though the latter may exert some influence in affording shelter against prevailing winds.

Finally, the pedological importance of *Micro-relief* must be taken into consideration. Micro-relief includes those small changes in the relief of an otherwise even face which are more often than not only noticeable after careful inspection. It is more intimately connected with local drainage than with either the altitude, aspect, or slope of the main topography. The soil types resulting from differences in micro-relief are frequently only those of the wet phase or the dry phase of the main soil type of the region. In semi-arid or arid areas and in waterlogged, or tidal areas, on the other hand, the importance of a few centimetres of rise and fall in relief may be directly responsible for an entirely different soil type. Good examples of features of micro-relief may be observed in the low ridges of coarse material which settle on the immediate edges of rivers and extend in decreasing quantity into the flood plain, or in erosion pavements, or again

on ancient ploughed land of the heavy ridge and furrow type now reverting into grass or woodland.

The general lie of the land both for main and mezzo topography may be obtained from the contour lines of the base map, or form lines may be drawn in on the xylonite cover[1] from a stereoscopic examination of overlap aerial photographs. The importance of this for field-work should be emphasized. When such help is not available, however, a surveyor may produce a very fair sketch-map with the aid of an Abney level, or a clinometer for the slopes, a pocket aneroid for altitudes, and a prismatic compass for direction.

Altitude measurements should be entered in metres, though the usual English Field Sketching Aneroid is graduated in feet. If possible work should be started from a spot height and the scale set; if this is impossible an approximate height should be assumed. On return to base the reading should be repeated, and if there is a difference the intermediate altitudes should be corrected in proportion to the time which has elapsed. A conversion factor of 3·25 ft. = 1 metre (Ht. $\times \frac{1}{3\cdot 25}$) will be found to be of sufficient accuracy.

Aspect is the direction taken by a bearing at right angles to the feature and should be accurate to the nearest sixteenth of the compass (ENE. or 22·5°).

Slope may be described by one of the following terms:

1. Steep	3. Concave
2. Gentle	4. Convex

with the use of 'uniform' or 'irregular' as qualifying

[1] See 'Indoor preparation for mapping', p. 145.

names. The amount of slope may be expressed either in 'degrees of slope' (i.e. number of degrees of inclination from the horizontal) or as a gradient. It must be remembered that slopes of 1° are of much greater importance to the pedologist than to an ordinary surveyor, since sheet erosion can take place quite easily if the soil be of the right type even on the smallest slopes. This subject is more fully discussed in the section on Field Mapping, p. 145.

The small grid diagram in the questionnaire should be used to show the relationship between the site and its surrounding topography in the form of a vertical section, or topographic profile.

Item V. Drainage.

There are two systems of drainage which must be defined as being of direct importance in a full description of the soil site—the main drainage system of the site and the drainage of the soil mass.

Regional Drainage. The drainage of the region is dependent upon the disposition and maturity of its watersheds and drainage basins. From observations of the direction, shape, and size of the streams much useful data may be obtained. The shape of the valleys is an important index of the maturity of the drainage, since old glaciated valleys are generally of the U type with steep sides and flat bottoms, while post-glacial valleys are generally of the V type and are due to more recent erosion by running water. Note should be taken of the liability of the area to seasonal flooding or to tidal inundation, and of the possibilities of sheet or gully erosion, evidence of

which should be looked for in out-wash fans of soil material on the lower-lying sites. Any artificial methods of protection or prevention should be described under Item VIII (Management). If streams are slow moving and in a lowland area, meander belts are frequent, with flood plain and alluvial deposits. A stream having reached its base line of erosion will intensify its lateral corrasion and tend to cut out meanders, ultimately widening its flood plain and decreasing the depth of the flood water and the effective transporting power of the stream. The frequency of the streams and whether they are free or locked (i.e. whether they are controlled in such a manner as to exert any effect upon the water-table) is always of importance. In correlation with the geology and topography, the height of the permanent water-table should also be found. Superficial drainage is mainly a function of the mezzo-relief, and is particularly important in the case of surface deposits of a heavy clay nature on slight slopes where the material is so impermeable that the surface run-off exceeds the direct percolation. The soils in such a region, even in a cool humid climate, frequently possess the characteristics of arid or semi-arid types in that they exhibit in their lower horizons concretionary or secondary calcium carbonate and sulphate.

Soil-Mass Drainage. Drainage of the soil mass is dependent upon several local factors, such as:

Local climate and vegetation.
Geological nature of the underlying rock.
Proximity of permanent water-table.
Texture of the soil mass (see p. 81).

Structure of the soil mass (see p. 87).
Constitution of the soil (see p. 107).

and the result may always be summed up under one or other of the following titles:

Excessive	(loss of bases probable);
Free	(satisfactory percolation and adequate retention of the natural precipitation);
Imperfect	(dense horizons to produce gley effects, but not anaerobic conditions or waterlogging);
Impeded	(Impermeable horizons to produce anaerobic conditions and stagnant ground water. Waterlogging).

Since, however, it is difficult to determine all the drainage characteristics of the soil mass without reference to the soil pit, it is usual to fill in this item of the questionnaire after the profile examination. It is taken here, however, to differentiate two soil sites which might be very similar in all respects except that one was the wet phase and the other the dry phase. The profile characteristics pertaining to water movement will be discussed in the course of the profile description.

Item VI. Climate (Rainfall, Wet and Dry Periods, Temperature, Winds, &c.).

The classification and geography of soils on the basis of climate is so widely known that little need be

said in explanation of this item. 'Climate' may be divided into main climate and local climate.

The main climate will, to all intents and purposes, be fairly uniform over a large area, and its influence may be accepted as a stable or invariable factor. Main climate is so obvious that in the ordinary selection of a soil site it is taken for granted. Local or micro-climate, on the other hand, is of very great local importance and is closely related to mezzo- and micro-relief and general edaphic features. The difference in local climate between the leeside and windward side of a shelter belt or topographic feature may be sufficient to produce some differences in the soil profile. Shelter can be responsible for a higher mean temperature or a lower evaporation sometimes associated with the establishment of a different plant association on the lee-side from that occurring on the windward side.

Rainfall. In those countries in which the distribution of the annual rainfall is uniform throughout the year a knowledge of its total amount is generally sufficient. In those countries in which there is a marked wet and dry season, however, a knowledge of the monthly distribution is absolutely essential, and especially is this so in the tropical and sub-tropical regions where surface evaporation becomes of great importance. No description is complete without these data, and it is better to state 'unknown' rather than to attempt to surmise a distribution on any geographical grounds. It is usual to express precipitation in millimetres, but the factor for conversion of inches to millimetres is approximately correct if taken as 1×25.

Temperature. Usually the mean annual maxima and minima and the periods at which they occur are sufficient, but if it is possible to obtain data with regard to the degree of humidity they may be of the utmost value for classification purposes.

Winds. The direction and nature of prevailing winds should be recorded, as they may exert an important influence on the soil formation. Exposure of the surface through lack of shelter may allow of desiccation and subsequent wind erosion.

In connexion with the amount of shelter given by various objects it is a useful general practice to assume that the effective limit of a shelter belt is usually about ten, but not more than twenty, times its height on the lee side, while an effective pocket may sometimes extend up to five times the height on the weather side. In the case of sloping objects like hills the effective range is much more difficult to assess since the wind tends to turn back upon itself and sometimes produces a vortex effect by sucking up air from the lee side greater in effect than the prevailing wind. Thus it becomes possible for a moisture bearing-wind to produce a dehydrating effect upon the lee side of a topographical feature.

If possible it should be determined whether the maximum wind intensity coincides with the maximum vegetational cover of the soil, i.e. during summer and autumn; or if the maximum intensity occurs at a season of the year when plant growth is at its minimum. The differences in soil and vegetation characteristics resulting from the various distribution periods is fairly obvious.

Item VII. Vegetation.

Since the soil and the vegetation which grows upon it are interdependent, it is desirable for normal survey work that the soil site selected should so far as possible carry a natural vegetation, or, if that is impossible, attempts should be made to ascertain what the vegetation would be if it had not been changed by human interference.

The vegetational climax[1] and the soil climax, if indeed such do exist, tend to occur and persist for some period of time dependent upon the evolution of, or the invasion by, another species of vegetation. The age of the site, therefore, will exert some influence on the type and stability of the vegetation, and this naturally becomes reflected in the morphological characteristics of the profile. The writer would recommend, therefore, that the surveyor be not too concerned with the definition of the various climaxes, but rather assume, from a study of the age of the trees or the history of the site, that at the moment of observation the natural vegetation and the soil are in equilibrium. In woodland regions, density and nature of the canopy is very important and may be calculated on the basis of 'complete canopy' being expressed as unity and all grades to 'open' or 'no canopy' being expressed as decimals of unity (e.g. 0·5 canopy). This system works out in practice, if, when the surveyor looks upwards he cannot see the sky, he records 'complete canopy' or '1'. If, on the other hand, he has an open view he records 'open

[1] See 'Use and abuse of Vegetational Concepts and Terms', Tansley, *Ecology*, vol. xvi, 3 (1930).

canopy' or 'O'. The importance of canopy or cover in the preservation of certain tropical soils is well known, while in the cooler zones the difference between coniferous canopy and deciduous canopy is shown in the different results produced in the soil profile by the rate of accumulation and decomposition of the leaf litter, under the various species. The relationship between rainfall, evaporation, and humidity in effecting characteristic changes in the soil profile is discussed in item VIII.

The density of the population of the various vegetational strata should also be assessed and noted, since the work of Tamm[1] suggests that the understory and surface vegetation are among the chief agents in organic soil formation.

For the assessment of the density of the vegetation use may be made of the Density Scales evolved by Burtt[2] during his botanical survey of the Tsetse Areas. His standards have been tried out in various other localities and for tropical survey in particular have proved to be of great value, both to agriculture and to forest officers. The following table shows how density is assessed:

D_1 Impenetrable thicket necessitating the cutting of a path.
D_2 Thicket penetrable without the cutting of a path.
D_3 Still so thick that a compass traverse is impossible without cutting a path. Grass covering usually about 10 per cent.
D_4 Visibility better. Grass covering usually about 20 per cent.

[1] *Medd. Statens Skogförs.*, 17. 49–300.
[2] *Roy. Entom. Soc. London*, vol. lxxxiv, 1936, p. 31.

D_5 Easy to traverse with compass. Grass covering usually about 30–50 per cent.
D_6 Grassland exceeding land covered by bush.
D_7 Scattered trees in otherwise open grassland.
D_8 Open grassland.

In practice, for categories D_4–D_7 the depth of visibility in yards provides a more suitable description.

By the term 'grassland' is meant 'ground not carrying shrubs, trees or tall herbs'; such ground may or may not actually carry grass, it may in fact be bare, especially in very dry country, or it may be covered by grass in scattered tufts only.

In the description of the vegetation for large-scale or regional reconnaissance survey the delimitation of the boundaries of the *Plant Formation* is very useful, and is generally sufficient, particularly in the case of the interpretation of air photographs. For site description, however, some smaller and more specific unit is needed. In ground survey the recognition of 'dominant' species sufficient to determine the *Plant Association* of the site is needed and is sufficient for most general purposes. It must be remembered, however, that the surveyor may, and frequently does, find different soil profiles occurring as small inliers or outliers under isolated *Plant Communities* and *Colonies*. It is, for instance, usually quite easy to detect local pockets of badly drained soils in the Brown Forest Soil zone by the sharp change from *Graminetum neutrale* of the Brown Soils to the *Juncetum* of the Marsh or Meadow Soils. The speed at which equilibrium between vegetation and soil is attained appears to be much greater than is generally recog-

nized, and the effects of a change of species can be reflected upon the profile in the space of a few years. An interesting example of this occurs in the neighbourhood of Oxford. About thirty years ago a series of plots was put down in old forest, comprising some eight varieties of conifers and a similar number of varieties of broad-leaved trees.[1] The soil is a quartzose gravel over clay, which at the time of planting out was a typical Brown Forest Soil fairly well drained, at an altitude of 100 metres and with an evenly distributed rainfall of 700 mm. Since 1920 these plots have been under the constant observation of the writer, and now (1938) all the coniferous sites are slightly podsolized, with each type showing a specific profile, while the broad-leaved sites have retained all the characteristics of the Brown Forest Soil, with a specific A horizon for each variety of tree. A. Muir[2] records a similar example in the Teindland State Forest.

In addition to the biochemical effects of the vegetation upon the soil mass, the physical effects are also of great importance. The expansion by growth of the plant roots—and more particularly is this the case with trees—exerts a definite pressure so that the soil structure and constitution undergo certain modifications. The surface of the soil becomes raised to produce slight differences in micro-relief, and in consequence a modification of the local or micro-drainage. Root pressure tends to alter both the shape and the size of the structural elements, so that lateral cracks

[1] 'Some Problems in Forest Soils,' Morison and Clarke, *Forestry*, 1928, vol. ii, pp. 14–18. [2] *Forestry*, vol. viii, 1934, pp. 25–55.

increase in number and tend to produce further changes in the constitution by increasing or decreasing porosity and compactness. Root channels, after the decomposition of the vegetable matter, allow of increased aeration and percolation, so that there is a consequent increase in range of the pedological processes.

Water- and heat-retention factors may be closely correlated with the surface vegetation when alive, and may sometimes be even more closely connected when the vegetation has become humus.

Item VIII. Man's Influence.

The story of man and his settlement on and use of the land has been admirably described by G. V. Jacks,[1] and because of the great importance of this aspect the following portion of his work is quoted *in extenso.*

'Soil and civilization types are not necessarily determined in the same way as soil and vegetation types, but since the evolution of a civilization is greatly influenced by the climate and vegetation the correspondence is fairly close. Had pedology developed as an offshoot of sociology rather than of plant ecology, soils would have presumably been grouped to conform to the great divisions in human, rather than in plant, history. That such a grouping would have been justified by actuality is shown by the fact that soil distribution according to Gedroiz's general chemical classification corresponds closely with the different historical types of civilization. Gedroiz's four main soil classes were:

1. Chernozem Type.
2. Alkaline Type.
3. Podsol Type.
4. Lateritic Type.

[1] G. V. Jacks, Monthly Letter, No. 67, 1937. Imp. Bur. Soil Science, England.

Most early civilizations were associated with the alkaline soil type, and depended upon irrigated agriculture. The effect of the human factor in soil formation was to leach soluble salts from the surface horizons and to convert serozem and solonchak into solonets, this effect being quite as "natural" as the effect of coniferous forest vegetation in leaching bases and sesquioxides. The analogy can be extended further. A podsolizing vegetation does not normally occur on soils resistant to podsolization (e.g. arid soils), and an irrigation civilization would not arise in humid regions where solonets formation was impossible. The mutual interdependence between civilization and soil is as strong as that between vegetation and soil. The nomadic hordes that swept over Asia and Europe destroying the irrigation civilizations were, like wild animal populations, too unsettled and transitory to leave a permanent mark on the soil, although their destructive conquests can be ascribed, at least partly, to soil, and consequently human, deterioration in the irrigated settlements.

'Again, unmistakable traces of past civilizations are found in Central America, Columbia, Ceylon, and the East Indies. These belonged to the laterite type, and their effect was to accelerate lateritization and erosion, until after relatively short times they had to yield again to the tropical forest. They represent failures of civilization to oust vegetation as the principal agent in soil evolution.

'The Asiatic alkaline-type civilizations were succeeded by the Mediterranean terra-rossa type, forming a transition to the more fully developed podsol type that dominates the world to-day. The basis of the podsol-type civilization is suppression of the forest, and it has never made much headway except on forest soils. It is still too early to speculate on the ultimate effect of the human factor on podsolic soils, but up till now it seems to have been a tendency to form chernozem-type soils, these being at once more productive, and less favourable to the hostile forest, than podsols. We cannot speculate, either, on the probable nature and effect on soil development of the chernozem-type civilization which is

already threatening to supersede the present one. One thing is certain, namely, that it must be entirely different, from its foundations upwards, from the podsol type. There are no forests to suppress, and so far the application of podsol-type science and principles to chernozem-type soils has chiefly resulted in rapid and often irreparable soil exhaustion and erosion. In the great grassland regions of the Old and New Worlds we can observe the initial stages of maladjustment between a stable soil type and a new biotic factor, to be followed by readjustment to a future equilibrium at which the soil will have exerted its full effect on human relationships, and another climax of civilization will have been reached.

'The prospects of a stable laterite-type civilization seem more distant; it is unlikely that white races can ever become sufficiently acclimatized to the tropics to form communities omnipotent over Nature, and the native races (which have failed more than once in the past) are not yet capable of subduing the tropical forest and replacing it by an equally efficient soil-forming agent in the shape of a settled civilization. But the yellow and brown races have left their mark on the serozems, the white races are remoulding the podsols and chernozems, and the time of the blacks must surely come in the end on the laterites. The laterite-type civilization will be essentially a conquest of the forest, and in the very distant future when it will have decayed and its nature may be seen in true perspective, it will probably be found to have been more closely related to the podsol type than to the coming chernozem type, which may be expected rather to resemble the alkaline type.'

Full notes are always well worth taking when considering this human aspect of the subject since man's utilization of natural sites is probably the most erratic and certainly the most rapid of all soil-forming factors. Man and his implements can, in the course of two or three seasons, reclaim a marsh to a meadow

or change a Brown Forest Soil to a Brown Earth, while in a slightly longer time he may reclaim and convert a Podsol into an agricultural Brown Earth. Man's influence is usually directed towards one or other of two main objectives, namely, either the alteration of the character of the soil in such a way that a change of the vegetational equilibrium is established, or the changing of the vegetation in such a manner that a change of soil condition will ensue. For the bringing into cultivation of virgin land all sorts of methods are available, but in all cases except those in which a soil and vegetation equilibrium is attained, soil degradation must inevitably follow. The necessity for the shifting cultivation of the tropics or the fallowing of the chernozems are good examples of natural regrading processes, while the necessity for the continuous manuring or artificial fertilizing of land under arable cultivation in order to maintain economic yields of more exacting species of vegetation is a common practice of modern farming. It may be assumed that the natural climax type of vegetation in the temperate zones is the broad-leaved woodland, and drastic changes may be wrought in this as a direct result of human influence. Firstly, man may change the type of the Woodland Formation by establishing a lower base demanding species of tree, with its complement of acidic humus and low base status in leaf fall, the ultimate end of which degradation would lead to the formation of the Podsolic soil type. Or, secondly, he may cut and clear the woodland and practice tillage. It is with the second system of utilization that we are more closely

concerned because it is more intimately connected with the needs of the human community. The chief soil components most susceptible to the influence of man are the water and the organic matter.

It is generally understood that in the broad-leaved forests of the temperate zone heavy canopy tends to depress surface evaporation, while the trees transpire water removed mainly from the ground water zone. It depends, therefore, upon climate, height of water-table and density and variety of canopy as to whether the dominant stream of soil water moves upward or downward. The first result of cutting and clearing of broad-leaved forest is to expose the surface of the soil to direct climatic influences and increased insolation and to upset the relation between the upper moist humic zone and the lower wet zone in the soil mass by the increased evaporation and drying out at the surface. At the same time, the even micro-climate of the forest becomes changed to the rapidly variable micro-climate of open areas. The loss of canopy and tree transpiration causes a rise in the level of the ground water. The exposure and increased insolation also brings about a more rapid decomposition of the organic matter so that the water-holding capacity of the surface layers becomes reduced. The percolating water received by direct precipitation then increases in its intensity and in a short time contact is made between the two moist zones: the drier B horizon which existed under forest conditions is now no longer dry. Such changes in the water régime alter the distribution in the profile of water-soluble substances, while the chemical and physical properties

of the organic matter are also affected. Such changes are generally adverse and are readily discernible in the field in the structural and constitutional features of the soil profile. The cessation of a leaf-fall of high mineral content and the consequent return to the soil of its material allows of an increase in the dissolving power of the percolating water with a tendency to a loss of bases. The loss of organic matter also represses the activities of earthworms, the presence of which is an important factor in the incorporation of organic matter in the soil mass. That the soil does not quickly degrade to a podsol is due in the main to three causes. One is that by regular cultivation the top zone of the soil is being continually inverted and the bases which tend to be leached downward a little way are thus brought back to the surface horizon. The second is that, by the removal of canopy and the reactions subsequent to it, the soil transpiration current is intensified so that a tendency towards the upward movement of salts and a salinization of the upper layers occurs. The third, and probably the most important, is again directly due to man's influence, in adding salts and organic matter to replace that removed from the soil in crops for his needs. The result therefore of cutting, clearing, and cultivating the natural forests of England is to change a stable Brown Forest Soil into a metastable Brown Earth.[1]

Further changes may occur on these metastable

[1] (*a*) 'The Brown Forest Soils of England', G. R. Clarke, *Forestry*, vol. vii, p. 43; (*b*) The Position of 'Brown Earth' in Soil Classification, Imp. Bur. Soil Science Report, Dec. 1937.

soils when kept in constant cultivation by a loss in quality of their structure, constitution, and base status. Base status can only be maintained by artificial management, while the retention of the highly desirable granular structure of the humus-cemented calcium-clay aggregates is only possible by the addition of humus and lime. Failure to provide for these demands leads to immediate further degradation, and ultimately either to infertility or the invasion of an undesirable type of vegetation in equilibrium with these soil conditions.

The maintenance of a good calcium-clay, coupled with its sufficiency of plant nutrients, and a granular structure is the acme of all economic agricultural utilization. Where such cannot be obtained, man must accept the soil he has got and make use of a *Formation* of vegetation, such as woodland or grass, which will attain equilibrium and thrive under these adverse conditions. Man may, however, use his soil to a wrong end and, when he does, disaster follows.[1] The following quotation is taken from Thorp and Hou's report on the 'Soils of China':[2]

'When we analyse the difficulties of erosion control and the failure in the past to really control this problem we come face to face with the fact that a very large share of the cultivated land of the Loess plateau should never have been plowed. Nature intended most of this land for grazing with a limited expansion of agriculture on the flat hill tops and in the river valleys. The tremendous pressure of population has resulted in an expansion into lands which cannot be expected to permanently support an agricultural population.

[1] See also 'Unnatural Pressure' on p. 89.

[2] *Soil Bulletin*, No. 12. Nat. Geol. Survey of China, 1935.

It is true that this land has supported farmers for a long period of time and some of it will continue to support a dense population for a long time to come, but we may be assured that the steep hill sides will ultimately become a complete waste and that many of the better lands on the hill tops will be dissected by gullies which will spread up from those which already exist. The best we can do at present is to encourage every effort that will delay the time when these lands will become unfit for cultivation. Some suggestions may be made that will help in this direction, but we cannot hope to completely prevent the destruction of land which has already been started by the shortsightedness of man.'

The reclamation of salt soils, the drainage of marshes, the irrigation of deserts, &c., all present their own difficulties and problems of ecology and pedology, and the field-man employed on any of these works will obviously have to undertake investigations which cannot possibly be more than hinted at in the scope of this small publication.

II

THE SOIL-PROFILE PIT

THERE is nothing new in the idea of the examination of a soil pit as a means of studying the soil *in situ*. The classic example of the soil pit occurs in Virgil's *Georgic*, *circa* 40 B.C., which, freely translated, may read: 'first choose out a place [soil site][1] and then order a pit to be dug where the ground is solid [true *in situ* material], then throw in all the earth again and tread it well down, if it does not fill the pit the soil is loose [i.e. constitution] and will abundantly supply the cattle and fruitful vines [crumb structure, adequate absorbed bases]. But if it refuses to go into its place again and rises above the pit that has been filled up, the soil is thick [texture and constitution], then expect sluggish clods [structure] and thick ridges [impeded drainage] and plough up the earth with strong bullocks.' Probably the only difference between Virgil's description of a soil pit and the profile description of a soil pit to-day lies in the fact that cheap paper allows the modern observer to record more observations than the older investigators, but there is no evidence to prove that they did not see just as much as any observers could do to-day. From Virgil's pit to the recorded soil profile takes us through about seventeen hundred years of effort with but little noticeable improvement, until Robert Plot, sometime Keeper of the Ashmolean Museum, and Professor of Chemistry in the University of Oxford, described the soils of Oxford and the profile

[1] Words in brackets are the present writer's.

of an ochre pit on Shotover Hill, near Oxford. In his *Natural History of Oxfordshire*, printed at 'The Theater in Oxford', 1677, he says (p. 52)[1]:

(*Par.* 3.) 'As to the qualifications of the Soil in respect of Corn, I find them in goodness to differ much, and not only according to their several compositions (being in some places black, or reddish *each*: in others a clay or chalky ground, some mixt of earth and sand, clay and sand, gravel and clay, &c.) but chiefly according to the *depth* of the *mould or uppermost coat of the earth*, and the *nature* of the *ground next immediately under it*: for let the uppermost mould be never so rich, if it have not some depth, or such a ground just underneath it, *as will permit all superfluous moisture to descend, and admit also the hot and comfortable steams to ascend*, [soil transpiration current of the Brown Earths and Red and Brown Calc. Soils] it will not be so fertile as a much leaner soil that enjoys these conditions.'

(*Par.* 4.) 'Thus have I often-times seen in the County, in all appearance a very good soil, and such indeed as would otherwise have been really so, less fertile because of its shallowness, and a cold stiff clay, or close freestone next under-neath it, than a much poorer land of some considerable depth, and lying over a sand or gravel, *through which all superfluous moisture might descend*, and not stand, as upon clay or stone, to chill the roots and make the Corn languish.'

(*Par.* 5.) 'Where, by the way let it be noted, that I said a cold stiff clay or close free-stone; for if there be under a shallow mould, a clay that's mixed (as 'tis common in the blew ones of this County) either with pyrites aureus, or brass lumps; or the stones be of the warm calcarious kind, it may nevertheless be fruitful in Corn, because these, I suppose, do warm the ground, and give so much strength, that they largely recompence what was wanting in depth.'

Then on page 55 he continues:

(*Par.* 14.) 'They dig it [the ochre] now at Shotover on the

[1] Italics and words in square brackets are the present writer's.

east side of the Hill, on the right hand of the way leading from Oxford to Whately, though questionless it may be had in many other parts of it; The vein dips from East to West, and lies from seven to thirty feet in depth, and between two and seven inches thick; enwrapped it is within ten folds of Earth, all which must be past through before they come at it; for the Earth is here, as at most other places, I think I may say of a bulbous nature, several folds of divers colours and *consistencies*, still including one another, not unlike the several coats of a Tulip root, or Onyon.

The 1. next the turf, is a reddish earth.
2. a pale blue clay.
3. a yellow sand.
4. a white clay.
5. an iron stone.
6. a white, and sometimes a reddish Maum.
7. a green, fat, oily kind of clay.
8. a thin iron-coloured rubble.
9. a green clay again.
10. another iron rubble, almost like Smiths cinders.'

This pit of Plot's is no longer worked, and, during the nearly three centuries of side-fall and soil creep, has completely disappeared. Other disused pits in the neighbourhood bear some slight resemblance to Plot's description, but do not justify a comparative description.

Preparation of the Profile Pit.

The required site being found and the characteristics recorded, the profile pit may be prepared. It is always better to make a thoroughly good pit while about it, since so often on returning one is apt to wonder if perhaps just another foot deeper might not have yielded still further information. The pit, there-

fore, should be made to a standard, and though it is often desirable that the surveyor should dig a certain amount in order to familiarize himself with the information obtained by the sound and feel of implements during the digging operation, it is obviously a waste of his valuable time for a qualified surveyor to be pit-digging when he could better be employed in further reconnaissance, sampling, &c.

The pit should be rectangular in plan, about three-quarters of a metre wide, at least two metres long, and as deep as is necessary to expose the parent material. The position when possible should be oriented in such a way that the light shines into the end of the pit and indirectly illuminates both long sides at the same time. The importance of this apparently small point will be dealt with later. The tops of the long sides should be preserved so that no trampling or puddling occurs (or structure and constitution may be adversely affected) and the waste earth should be thrown clear over the ends of the pit. The long sides of the pit may now be 'faced' and may be examined and recorded 'fresh', but as good structural and constitutional features do not usually appear until the soil has dried out somewhat it is perhaps better to leave the whole pit to dry out a little.[1] When the faces have dried out sufficiently one face may be picked with the fingers or a small knife-blade so as to bring out the characteristics of the structural elements, while the other face may be cut

[1] Practical difficulties may arise in soils with high water-tables or on wet sites, but by means of sump holes and a pump most of these may be overcome. In the case of marshes and swamps, however, monoliths may be taken from the fresh pit and allowed to 'structure up' in the laboratory.

back to a 'fresh' appearance. During this latter operation the soil removed by each cut of the spade should be thrown out separately and carefully examined for structure, &c., as a corroboration of the detail to be observed in the picked face. It is noticeable in a profile study that certain characteristics show up better in the loose fragments than in the picked face, e.g. grain and nutty structures are usually more clearly defined by the jolting of the mass of earth as it is tossed on to the ground, while prismatic or columnar structures are usually better seen *in situ*.

THE SOIL-PROFILE DESCRIPTION

The first operation in the examination of the soil profile is to divide it into its different layers, horizons, and zones by means of any visible characteristics and to determine their names. The description then proceeds by visually analysing and recording the characteristics of each layer in the following order:

1. Horizon name.
2. Definition of boundary.
3. Colour.
4. Carbonates or none.
5. Texture (frequency and size of uncemented mineral fragments).
6. Organic matter (form of and penetration).
7. Structure (size and shape of cemented fragments).
8. Consistence, porosity, tenacity.
9. Proportion of mineral skeleton, size and shape of stones.

10. Special characteristics:
    Degree of moisture.
    New chemical deposits.
    Acidity as pH value.
    Drainage characteristics.
    Root penetration and development.
    Effects of fauna.

1. HORIZON NAME (*Layers, Horizons, and Zones*).

In the horizonal differentiation of the soil profile the chief genetic divisions have the appearance of layers, and it is often convenient in the field to record the profile as Layer I, Layer II, &c., from the top to the bottom. If, however, it is possible to differentiate the layers by their genetic characteristics, use may be made of the horizon and zonal symbols: A, B, G, C, A–C, and numerals 1, 2, 3, &c. The use of symbols is usually applied to the descriptions of all soils except those in which horizons are formed by an upward-moving, salt-bearing, transpiration stream. The reason for such a convention will appear in due course.

Horizons.

The A Horizon. A is the surface horizon which is in direct contact with climatic influences. It tends, under precipitation of rain, to lose certain soluble salts by drainage, and sometimes to lose fine particles of insoluble material by mechanical down-wash. It is essentially a horizon of eluviation. (In the alkali soils this A horizon is called the 'surface layer' to avoid confusion, since in this case a horizon of eluviation

does not generally occur, except in certain of the Solod types.) In most soils the A horizon shows subdivisions within itself, and these are described by adding a numeral to the initial letter, starting with A_1 at the top and proceeding downwards until the next genetic horizon is reached. Such subdivisions are termed zones (e.g. 'The A horizon possesses three zones A_1, A_2, A_3').

The A horizon is frequently overlaid by layers of vegetable debris (sometimes described as A_0) which in the past have been somewhat loosely named as humus layers, leaf-litter, leaf-mould, &c., and some doubt always existed as to the manner in which such material should be described. Using the Swedish term Förna (see p. 71 et seq.) for such surface material, Hesselman has divided this into layers or zones under the letter-name headings of F and H. In a manner similar to that of the division of the A horizon in A_1, A_2 zones, &c., the F horizon may be subdivided into F_1, F_2, &c., dependent upon the progressive decomposition with time of the annual leaf fall. When decomposition has proceeded to the extent of the loss of the botanical structure of the vegetational debris and the mass is truly humified, the horizon is designated as H. The manner in which the symbols F and H are used may be explained in the following description of the organic profile of a spruce stand by Mattson and Ekman.[1]

F.00. Green needles picked from tree (i.e. living vegetation).

F.0. Dead needles shaken from tree.

[1] *Trans. 3rd Internat. Cong. of Soil Science*, 1935, vol. i.

F.1. 0–1 cm. near trunk of tree.
F.2. 7–10 cm. structure largely preserved.
F.3. 12–15 cm. colour still light but structure partly destroyed.
H. 18–22 cm. black, structureless humus.

Beneath the H layer the soil profile properly begins with the A horizon which is dominantly of mineral origin.

The B Horizon. B is essentially an illuvial horizon, or a horizon of accumulation of the materials derived from A. Such materials accumulate both by mechanical inwash and chemical deposition. In certain soils, however, an accumulation horizon is formed from below by an upward current of salt-bearing water (i.e. the soil transpiration current), and which, though illuvial, is not usually termed the true B horizon, but is numbered as a unit in the 'layer' class of soils. Subdivisions of B are numbered exactly as in horizon A (i.e. B_1, B_2, B_3).

The G Horizon (or more frequently the G zone).[1] The symbol is the initial letter of the word 'Gley'. 'By the word "Gley"[2] the people understand a more or less compact loamy or clay rock of a grey colour but less plastic and less sticky than usual. It frequently has a more or less clear, yet weak, greenish blue tint.'

The above quotation is from Vysotzky in *Gley Pochvovediniye*, 7, 1905, p. 291. Since that time, however, the term has been used by pedologists in a much wider sense and to apply particularly to the description of a specific set of soil-water characteristics. The colours of the zone are characteristic of the effects

[1] G. R. Clarke, 'Brown Forest Soils of England' (*Forestry*, vol. vii, no. 1).
[2] Pronounced to rhyme with 'clay'.

produced by the alternate reduction and oxidation, hydration and dehydration of iron and manganese compounds by the fluctuating rise and fall of the ground-water and soil-air zone. Pale blue, green, and yellow mottlings, as patches and streaks, occur both *in* the soil *mass* and *on* the *faces* of the structural elements. In soils with sufficient clay to possess structure the elements of the Gley zone possess a structure peculiarly their own, which resembles a triangular prism resting horizontally on a face or an edge in such a way that the inter-unit drainage channels are inclined to the vertical. The varnished-like faces possess an almost metallic lustre upon their inclined sides which, the writer suggests, may be produced by the polishing friction between the faces of the elements as they expand and contract and rise and fall with the rise and fall of the ground-water. It has also been suggested by Rodé[1] that the polish is caused by the downwash of fine clay into cracks formed during dry weather. The characteristic Gley zone is not confined to any special depth in the profile, but, being dependent upon the rise and fall of the ground-water, it is essentially a zone of alternating oxidation and reduction, and, in consequence, is more frequently to be found in ill-drained, marshy, or meadowland profiles.

The C Horizon. C is the mineral material of geological origin which, under the influence of environmental factors, is forming true soil horizons as the soil develops.

[1] Lisino Experimental Forest Excursion. Dokuchaiev Inst. of Soil Science, Leningrad, 1930.

The A–C Horizon. In certain soils, particularly those derived from soft limestones, the rock weathers to form A and C horizons only, and there appears to be no development of a true B horizon. The calcium carbonate increases both in quantity and size of fragments from the top of A to the bottom of C. A horizon which has the properties of the mean of the A and C horizons may be found, and is termed the A–C horizon, since no horizontal boundaries can be determined. It is essentially a characteristic of Rendzinas and skeletal soils.[1]

2. BOUNDARIES.

Boundaries are defined by their clarity and are measured in centimetres.

'Sharply defined' when boundary occurs through not more than 3 cm.

'Clearly defined' when boundary occurs through not more than 5 cm.

'Gradually merging' when no very definite boundary occurs and the junction ranges over more than 5 cm.

3. COLOUR.

Soils derive their colour from two sources:

Organic Matter	*Mineral Matter*	
Black	Iron	Red, Orange, Yellow. Brown, Blue, Green
Brown	Ca	White, Yellow-white
Grey	Mn	Black or Brown

Pinks, mauves, and purples may also occur, due to other minerals, but these are not common enough to

[1] Velten, E. C. W., and Clarke, G. R., 'Report on Cotswold Soils', Ministry of Agriculture Soil Survey Conference, 1934.

discuss at length. Various attempts have been made to correlate colour with fertility, but so far no very conclusive results have accrued.

The various coloured compounds of iron are due mainly to the degree of oxidation and hydration, though other compounds exist, such as vivianite, which gives a blue colour to certain of the wet, water-logged soil varieties.

The hydrated ferric oxides are believed to be:[1]

Turgite	Fe_2O_3, $\frac{1}{2}$ H_2O	Red to Red-brown
Goethite, Lepidocrocite	Fe_2O_3, H_2O	Brownish-black, Yellow and Brown
Hydrogoethite	Fe_2O_3, $\frac{4}{3}$ H_2O	
Limonite	Fe_2O_3, $\frac{3}{2}$ H_2O	Yellow and Brown
Xanthosiderite	Fe_2O_3, 2 H_2O	Golden-yellow-brown
Limnite	Fe_2O_3, 3 H_2O	

There appear to be two series of colours:[2]

Reds formed by the precipitation of ferric salts by alkalies.

Yellows formed by oxidation of ferrous oxide and carbonate.

Some more recent work on these coloured compounds of iron by Weiser[3] goes to show that only the monohydrate is stable and that the compounds Fe_2O_3, n H_2O, exist in the form of solid solutions.

Van Bemmelem[4] suggests that the red-brown substances are not true hydrates, but are colloids, and that their colour is dependent upon the surrounding vapour pressure.

[1] Posnjak, *Amer. Journ. Sci.*, xlvii, 1919, pp. 311–48.

[2] Tomasi, cited in same paper.

[3] H. B. Weiser, 'The Colloidal Hydroxides', *Inorganic Colloidal Chemistry*, vol. ii, 1935.

[4] *Die Absorption*, pp. 70–7.

In support of such hypotheses it is noticeable that the colour range of soils over the main climatic zones tends to proceed from browns and yellows in the cool and humid zones to reds in the subtropical and tropical humid zones, where rapid drying out of the dominating soil transpiration current is the rule. The Red and Pink Insubrische Soils of Switzerland on the southern slopes of the mountains are characteristic colour products of such situations and, like the Terra Rossa, may be looked upon as the link between the Brown Soils of the temperate zone and the Red Soils of the tropics. At the same time, however, this is not the entire story, for analysis of these soils shows a progressive increase in the iron content in the following general order: Podsol (A_2) $<$ Grey Forest (A) $<$ Brown Forest (A) $<$ Terra Rossa (A) $<$ Laterite.

Whatever the true explanation of these colours may be, their permanence is dependent to a certain extent upon the humidity of their environment. For, if certain red tropical soils are stored as monoliths in a cool humid environment they tend steadily to lose some of their redness and to assume a yellowish tinge. Prolonged dehydration at a low temperature, however, tends once more to restore the sample towards its original colour.

In colour descriptions, it is helpful if the chief cause of the soil colour can be ascertained. For instance, a horizon may be black either from an accumulation of manganese dioxide or from humified organic matter, and a soil type may sometimes be defined on such evidence alone.

The angle at which light illuminates the soil may

cause apparent colour changes due to reflection and absorption. The length of the shadows cast by the soil particles in the texture and structure of the soil mass also produces peculiar effects. Red soils tend to look redder in the afternoon than in the morning, while some soils may differ when looking uphill or downhill and towards the sun or away from it. Such optical problems as these form one of the chief difficulties yet to be overcome by the aerial soil-surveyor. It is better, therefore, when determining the colour of the soil in the field, not to view a large mass over a wide area, but rather to view it in short focus. Take a handful of the soil and wave it gently in various directions so that a *general impression* is gained. In addition to this general impression of colour, notes should also be made of the character or forms in which the colours are distributed. Colours tend to occur in some sort of order and may be classified by some simple system such as the following:

a. Self-coloured. The whole horizon is homogeneous.

b. Speckled. Small particles of various colours fairly uniformly distributed in an otherwise self-coloured matrix.

c. Streaky. Colourings are dominantly vertical.

d. Rippled. Very small, dominantly horizontal markings.

e. Waved. Large, dominantly horizontal markings of an undulating nature.

f. Banded. Large and generally flat and even.

g. Cloudy. Large ill-defined patches which merge without definite boundaries.

h. Mottled. Multicoloured particles in a generally cloudy mass. Entirely different to 'speckled'.

For example, in the description of an ill-drained Forest Soil it could be stated that:

> The B horizon was brown, speckled with red, and streaked with dark brown; while the G zone was cloudy yellow-brown, with a green mottle.

A perfect set of standard soil colours has not yet been evolved, and the observer must make what colour descriptions he can devise to give a general indication. The use of the Ridgeway Colour Atlas is now recommended by the English Soil Survey Conference, but its use does not do away with the difficulty of varying lights, moisture contents, and the masking effects of mixed fragments. In this connexion, however, it would greatly assist field descriptions if some few general colours were standardized and named so that when a soil in the field is termed 'red' it means something which all field-men could recognize. In England a very useful system for field determination has been evolved by D. A. Osmond. The principle of the method lies in comparing colours of the soil in the field with a set of standard soils mounted on cards in a cellulose fixative. The cards are about the size of postcards with a small rectangular aperture cut in the centre the size of the Ridgeway colour blocks. The cards are standardized against Ridgeway before the field-man starts out on survey. In the field he spreads a sample of the soil behind the aperture and checks up to the nearest colour match. The moisture condition of the sample does not matter since the

colour is checked as found. Thus the wet and dry phase of the same soil would require the use of two colour cards. The method, though simple to use, is undoubtedly an advance on anything yet devised for field work. A description of the method for the making and use of the cards is given in the appendix.

The soil colour should be noted both in the wet and dry states, though in the field it is quite useful to determine it at its sticky point, since some black soils may dry out almost white. The masking of one colour by another is common in organic soils, and it is often convenient to oxidize the organic matter with hydrogen peroxide and record the colour of the residual mineral material to verify a suspected translocation of iron.

Since the field-man in assessing texture has to salivate and moisten a soil fragment between his fingers he may well use the paste so made to make a colour smear of the horizon on his profile sketch. The colours so obtained are remarkably stable and though crude may greatly assist the memory when writing up the fair copy of the profile description. This method is, in fact, commonly used in Russia and Tanganyika.

The classification of soil colours in the laboratory is an entirely different matter, and will not be further discussed.

4. Carbonates.

A little acid is poured down the profile over the 'fresh' face, and the points at which reaction commences or ceases are noted, as is also the intensity of the reaction. Carbonates may be present either as

relics of weathered parent material (limestone or dolomitic rock fragments) or as new pedological deposits (such as the carbonates of soda, lime, iron, or magnesia), the size, shape, and quantity of which should be recorded under their respective headings.

Care should be taken to differentiate between concretionary or deposited material and relic parent material. Concretions will, on fracture, show some tendency to concentric formation and, though they may possess curious shapes in aggregation, the general form of the separate units is spheroidal. White fluffy or powdery patches and pseudo-mycelium of calcium carbonate are often to be found together with concretionary materials in certain soils, but whether one is merely a stage in the development of the other it is difficult to determine. Crystalline calcium carbonate as calcite or aragonite is frequently to be found in A–C and C horizons of certain of the Red and Brown Limestone soils of the Rendzina or Terra Rossa types, due to the downwash of dissolved carbonate from the surface into the interstices of the lower horizons which are already saturated with the products of hydrolytic weathering. Subsequent dehydration produces either the powdery or the crystalline form of deposit, but the writer has never observed the hard spheroidal concretions in these types of soil.

Calcium sulphate frequently appears in the form of crystals in the profiles of certain soils of the cool humid regions as well as in the grass steppes and savannah regions. These crystals of gypsum are usually plainly visible either in layers or pockets and may occur either as twin crystals (earth hearts) or as plates.

The appearance of concretionary or deposited carbonates and gypsum in the soil profile may always be correlated with basic ground-water and a soil transpiration current, so that a soil type may often be recognized from such observations alone. Relic carbonates will of course resemble the structure, texture, fracture, and chemical characteristics of the massive parent rock, and can usually be recognized even in a fairly fine state of division by means of a pocket lens. Failing this, however, it may usually be found that new calcium deposits are very much more easily soluble in dilute acid, are purer, and, in consequence, do not leave so large an insoluble residue of clay, iron compounds, or silica, as a similar quantity of parent rock.

5. Organic Matter (*Form and Disposal of*).

The organic portion or the 'humus profile' of the soil is a manifestation of the biological reactions involved in the soil-forming processes. By a careful study of the visible evidence available from the soil humus profile, much information may be obtained in regard to the soil's life-history. Since the main portion of the humus of the soil profile is derived from the surface vegetation, either by leaf-fall or root decay, the nature of the leaf litter, grass mat, or vegetable debris should be examined and measured. The effect upon the soil profile produced by 10 cm. of oak litter will be very different from that produced by 10 cm. of spruce litter, and such differences should be easily detectable by an observer. The approximate age of accumulations of leaf litter may sometimes be determined by carefully folding back, layer by layer, the annual leaf-fall until

the botanical structure of the leaves becomes vague and merged into the 'raw humus' layer of acid soils, or the 'mull' layer of the less acid and neutral soils. The problem of what is or is not 'humus' in soil nomenclature is too controversial to discuss in the field, where conclusions can only be drawn from physical observation of colour or structure changes and the reaction with hydrogen peroxide. The phrase 'organic matter (form and disposal of)' in the profile questionnaire will suffice for most field work. Hesselman uses the term 'Förna' for all that plant material of undecomposed leaf-fall and litter which has not broken down into the darker and more compact 'vegetable mould' with the loss of its botanical structure. If the observer records, however, as 'litter' that accumulation of loose unrotted vegetable material which retains its position by gravity alone he will not be far from most of the generally accepted ideas.

There are three main types of 'Humus' which can readily be recognized in the field:

1. Raw Humus, Acid Humus, or Mor.
2. Mild Humus, Neutral Humus, or Mull.
3. 'Intimate' Humus of the Soil Mass.

Such divisions depend primarily upon the differences in the botanical and chemical nature of the vegetational parent material and the manner of its decomposition and disposal.

Raw Humus is characterized by its excessive accumulation (slow decomposition), capacity for shrinkage, and, frequently, by the presence of some structural remains of plants. A certain degree of lamination may sometimes be observed in the horizons of soils of the

slightly podsolized type, wherein the raw humus zone shows the 'clearly defined (3–5 cm.) boundary' to the truly pedological A_1 zone. Raw humus, though characterized also by an extremely low base content, does not show this in the field except in so far as granular structure is definitely absent, and unless the observer uses a pH outfit he is left with only what he can see from which to draw his conclusions. The writer cannot recall ever having observed raw humus with a pH value less acid than about 4·5.

Neutral Humus or *Mull*, on the other hand, though usually acid in reaction, contains sufficient absorbed calcium to allow of a crumb or grain structure with a generally 'loose' or 'porous' constitution. The black organic material is usually more intimately mingled with the soil mineral particles to form indistinct and merging boundaries ($>$ 5 cm.). The pH value of such mull layers varies from about pH 4·5 in the Brown Forest Soil types up to about pH 7 or just over in the Rendzinas.

Hesselman, and Romell and Heiberg have evolved systems for the classification of Forest Soil Humus Types. The following outline of the vocabulary of Romell and Heiberg is taken from their paper in *Ecology*, vol. xii, no. 3. This classification, however, has been evolved for the forests of the cooler and more humid climates and does not necessarily apply to those of the tropics.

Romell and Heiberg make use of certain of Hesselman's names in their main groups, such as: Hesselman's 'Förmultningsskiht' or decomposition layer is designated as F, while his 'Humusämneskiht' or

humic matter layer is designated as H. They continue to use the term 'Mull' but change the term Råhumus or Raw Humus to 'Duff'.

'*A. Mull.* A porous, more or less friable humus layer of crumby or granular structure, with diffuse lower boundary, not, or only slightly, matted.

1. *Crumb Mull.* A coarse-grained mull, inhabited by large earthworms, usually in large numbers. This is the classical prototype of the mull group. Content of organic matter usually around 10 to 20 per cent. or even lower, rarely over 30 per cent. Rich herbaceous vegetation, in which a spring flora of geophytes such as *Corydalis*, *Mercurialis*, *Anemone*, *Arum* (Eu.), *Dicentra*, *Dentaria*, *Hydrophyllum*, *Claytonia*, *Arisoema* (Am.), enters as a characteristic element. Litter of loose leaves, or at times practically none because of the rapid decomposition.
2. *Grain Mull.* Differs from the crumb mull by its finer granular structure and the absence of *large* earthworms. Flora like the preceding, but mostly poorer.
3. *Twin Mull.* A complex type of humus layer, consisting of one upper stratum with the characters of matted detritus mull or root duff (see below), underlain by grain or sometimes crumb mull. Flora poorer than on the preceding types, but includes mull plants.
4. *Detritus Mull.* A finely granular mull, rich in organic matter (usually over 50 per cent.), looking like black sawdust. Flora variable, but always including mull plants.

B. Duff. A humus layer of unincorporated humus, strongly matted or compacted, or both, distinctly delimited from the mineral soil, unless the latter has been blackened by washing in of organic matter. Flora usually completely lacking typical mull plants.

5. *Root Duff.* F-layer poorly developed, usually practically absent. Humus of the H-layer finely granular, like detritus mull; when dry, it can practically all be shaken out from the dense root mat which holds it together. Essentially a hardwood type.
6. *Leaf Duff.* Laminated F-layer of matted leaves, H-layer much like the preceding. A hardwood and hardwood-conifer type.
7. *Greasy Duff.* F-layer usually relatively little developed, often more or less fibrous, H-layer thick (usually 1 dm. or more), compact, but usually not very tough, partly or entirely black, muck-like, with a greasy feel when wet, shrinks strongly upon drying.
8. *Fibrous Duff.* F-layer well developed; entire humus layer fibrous, more or less tough, but usually not very compact, showing little shrinkage upon drying. The flora of the most typical forms includes Hylocomia or Ericaceae (particularly *Vaccinium*), or both.'

Since the publication of the above work by Romell and Heiberg, Romell and Bornebusch have produced yet another system for the classification of surface organic matter. Their system shown below was discussed and accepted with certain minor reservations at a meeting of the Forest Soils Sub-Commission of

the Third International Congress of Soil Science in Oxford, 1935, and is given in full in vol. iii of the *Transactions*.[1] It has also been accepted by the Union of Forest Research Organizations. Bornebusch and Heiberg, 'Nomenclature of Forest Humus Layers'.[2]

I. The definitions of the kinds of forest humus must, in accordance with P. E. Muller, be based on morphological characters which can be easily observed directly in nature.

II. Two main kinds only are to be recognized: 'mull' and 'mor'.

III. *Mull*: mixture of organic matter and mineral soil, of crumbly or compact structure, with the transition to lower layers not sharp. Three forms are recognized:

(*a*) *Coarse mull*.[3] Coarse grain structure, organic matter very conspicuously mixed with mineral soil (usually 5–20 per cent. organic content; exceptional cases even considerably higher).

(*b*) *Fine mull*.[4] Fine grain structure. Organic content high (usually over 50 per cent.).

(*c*) *Firm mull*. Dense compact structure, usually low content of organic matter, often less than 5 per cent.

IV. *Mor*. Organic matter practically unmixed with

[1] Thomas Murby, London, 1936.

[2] By forest humus layers is understood the top layer of the soil, owing its characteristic features largely to its content of organic matter. This part is often described as A_0 and/or A_1.

[3] At the Congress in Nancy of the International Union of Forest Research Organizations in 1932, the V Section adopted 'true mull' for this form.

[4] V Section adopted 'superficial mull' for this form.

mineral soil, usually more or less matted or compacted. Transition to mineral soil always distinct. Often composed of two layers named (after Hesselman),[1] F-layer, i.e. fermentation layer, resting on H-layer, i.e. humified layer.

The F-layer consists of more or less decomposed litter, still recognizable and with rather loose structure.

The H-layer consists principally of finely divided organic matter mostly unrecognizable as to origin. Structure more or less dense.

Three kinds of Mor are recognized:

(*a*) *Granular mor.*[2] H-layer pronounced and fine granular in structure; lower part somewhat compacted. In dry condition, very easily broken into fine powder when pressed by hand.

(*b*) *Greasy mor.*[3] F-layer usually relatively little developed, often more or less fibrous. H-layer thick, compact, with a distinct greasy feel when wet, hard and brittle when dry.

(*c*) *Fibrous mor.*[4] F-layer well developed. Both F- and H-layers fibrous but not compact. Many plant remains visible also in H-layer.

[1] The following definitions for F- and H-layers are not exactly in accordance with Hesselman (1926).

[2] By forest humus layers is understood the top layer of the soil, owing its characteristic features largely to its content of organic matter. This part is often described as A_0 and/or A_1. H-layer described as 'fine humus'.

[3] As above, note 2. This part is often described as A_0 and/or A_1. H-layer described as 'greasy humus'.

[4] As above, note 2. This part is often described as A_0 and/or A_1. H-layer described as 'fibrous humus'.

The classification of surface organic matter is not entirely complete without some reference to the various forms of peat. A simple system of classification has been drawn up by G. K. Fraser[1] dependent mainly upon the appearance and behaviour of the material during handling. Fraser defines three main types:

A. *Pseudo-fibrous peat.*
Soft and plastic, rigidity and tenacity lost, fibrous in appearance only.
 (*a*) *var. cheesey peat.*
 Rigidity partly maintained under intermittent aeration.

B. *Fibrous peat.*
Tough and flexible composed of scarcely altered remains of plants.

C. *Amorphous peat.*
Showing no recognizable plant tissues.

(A) *Pseudo-Fibrous Peat—Characteristic of Scirpus Moor.* Pseudo-fibrous scirpus peat is a structural peat, being composed of recognizable remains of scirpus, sphagnum, and other plants. Of these remains the stems and roots are easily visible, so that the peat has a fibrous appearance. It is, however, quite plastic since the apparently fibrous structures have undergone fundamental changes so that their strength and tenacity are completely lost. The organic matter as a whole has so altered that the peat acts in the same way as gelatine, i.e. it is capable

[1] G. K. Fraser, *Studies of Scottish Moorlands in relation to Tree Growth*, 1933. Forestry Comm. Bull. No. 15. H.M. Stationery Office.

of absorbing a large quantity of water and swelling considerably, and, on the other hand, shrinking to a remarkable degree when slowly dried. This change in the plant remains takes place only in the complete absence of air, and it is important to note that if pseudo-fibrous peat is exposed to the air, i.e. if conditions for aeration are established, changes take place by which the fibres regain their strength and the peat becomes fibrous, while the gelatinous matrix shrinks into black grains or brown encrustations upon the fibres.

(B) *Fibrous Peat—Characteristic of Calluna Moor.* The nature of fibrous peat has already been indicated in the above section. Fibrous peat includes those structural peats in which the strength and tenacity of the original plant tissues are retained (ordinary peat used as fuel is mostly fibrous in character), and for this reason fibrous peat shrinks to a much less extent than pseudo-fibrous peat. It is not markedly different in appearance from the turf below which it occurs.

(C) *Amorphous Peat—Characteristic of Molinia Moor.* By amorphous peat is meant that in which the processes of decay have gone so far that a form of true humus or mould has been produced from the peat-forming plant remains. In this kind of peat the remnants of plant structures are not any more visible than in the organic matter of an ordinary soil. Amorphous peat is dark brown or black in colour, and is composed of small particles indistinguishable from very humose clay soil, but of course it contains little or no mineral particles. The amorphous peat of molinia moor varies from a black mud-like peat mass,

which on drying becomes granular in appearance, to a brown-coloured peat of spongy texture which in its dry or wet condition is similar in appearance to well-rotted farm-yard manure.

Intimate Humus. This material is found truly incorporated in the soil mass and varies in colour from black—through the browns—to greys. Such material is responsible for the characteristic colours of the Chernozem, Black Cotton, and Brown Forest Soil types. Intimate humus is not necessarily confined to the A horizon but can be found dispersed and recoagulated in the B horizon of Podsols, Vleis, and certain other of the ground-water soils. Highly decomposed intimate humus is frequently to be found in certain of the red and yellow tropical loams with black or grey surfaces. Certain other tropical soils show no visible humus whatever, neither do they effervesce with peroxide in the field, though they may contain organic matter by carbon estimation in the laboratory. This intimate humus has more bearing upon the structure and constitution of soils in general than either of the preceding types, and particular care should be taken in its recognition and delimitation. Since it is so completely united into the soil mass, pH measurements do not necessarily represent it, so that hydrogen peroxide and the visible characteristics are the only criteria for its description.

The description of the incorporated soil organic matter commences at the A_1 zone: its disposal around the soil particles, in interstices or in the body of the structural elements, should be noted. The degree and nature of cementation should also be determined by

the sense of touch. Differentiation between cementation by humic or mineral material can usually be accomplished in the field either by means of acid, hydrogen peroxide, or a pocket lens. The extent to which humus is dispersed, mobilized, or transported down the profile is generally fairly easy to see. Calcareous soils tend to fix or immobilize humus near the surface, whereas leached and unsaturated soils tend to disperse and mobilize the humus down the profile into a secondary horizon. Sometimes basic ground-waters are responsible for the very black stain observable in Fen, Vlei, and Alkaline Peat soils. The colouring and mobility of humus in Saline and Alkali soils depends much more upon the moisture, sodium content, and the permeability of the soil mass than upon the actual quantities of humus present.

In delimiting the penetration of humus down the profile it is often convenient to pour a little peroxide down the freshly cut face when effervescence ceases at the limit of intimate humus penetration. In this connexion, however, it should be pointed out that commercial peroxide usually contains acid and so will react with carbonates. This method may also prove erroneous in the field in the presence of concretionary (i.e. pedological) manganese, unless the precaution is taken to differentiate between the two. Concretionary manganese is usually only crushable between the thumb nails and with a certain degree of force; elementary carbon is softer and usually structural. With peroxide, manganese usually reacts much more violently than does humus, and if the reaction is carried out in the palm of the hand the burning sensa-

tion may be quite definite and a little experience quickly teaches the technique. The streak on a piece of rough porcelain is also a satisfactory test (see p. 118). Elementary carbon does not react with peroxide and can rarely be mistaken on account of its position in the profile, its general appearance, and its easy crushability to form a black powder on the least pressure between the fingers. Geological carbon (i.e. coal or lignite) may be observed in certain soils derived from the Carboniferous series, but its recognition is easy owing to its adventitious distribution in the soil mass and by its physical properties.

6. Texture.

The term texture has been used in the past in a loose manner to include almost all soil characteristics such as texture, structure, constitution, and even workability. It now refers specifically to the inorganic solid material of the soil mass which includes the smallest particles, rock fragments, minerals, &c., obtained by mechanical dispersion or disintegration of the soil aggregates without, however, progressive comminution. The texture thus defines the relative amounts of coarse and fine material present in the soil mass and must not be confused with the structure or the constitution. The total area of the surface of the soil particles increases rapidly as the particle size diminishes, and this increase in surface has a considerable effect upon cohesion in the soil mass. Another property of the soil mass which is influenced by texture, as well as by structure and constitution, is the magnitude of the interparticle space. Thus texture,

including the amount of ultra-fine or colloidal material possessing a high degree of hydration, determines the water relationship of the soil. The terms 'clay soil', 'sand soil', &c., in a texture description refer to the dominating proportion of particles within a certain size-range, and bears no relation to any other characteristic. It is important to attempt to assess the texture of the mineral portion of the soil without regard either to the degree of particle-aggregation or to the quantity of organic matter present.

In different countries various systems for field definition of particle sizes are available, but the American and English systems have been elaborated to fit in with the special systems of Textural and Series Soil Surveys in progress in these countries. In most other countries where Pedological or Agronomic Utilization Surveys are in progress the field description of texture is confined to a very rough three-divisional system of sand, loam, and clay. This is not quite so crude as it may first appear, however, since, in a pedological description, texture has not quite the same significance in the field as in the laboratory. The difference is due to the fact that in the definition of certain classes of soil such as vegetable moulds or Rendzinas, the actual size of the dispersible inorganic material in the laboratory has not the same significance as the size of the undispersed or aggregated inorganic particles of the soil mass in the field.

The English System of Textural Classes. In the English system of soil survey classification, which is a simple modification of the American system, the Series[1]

[1] Series defined in Section IV.

name is usually a place-name, while the Type is determined by the addition to the Series name of one of the following textural classes or grades. The capital letter denotes the main texture, while the small letters a, b, m, &c., are qualifying names denoting light, heavy, or medium respectively.

Sands	Sa	Sb	
Loams	La	L (m)	Lb
Silts	Za	Zm	Zb
Clays	C	Cs	Sc
Chalk	K		
Peat	Pt		

The actual percentage composition of each of the various particle sizes to constitute the special type names has not yet been fully worked out, but experienced surveyors agree remarkably closely in their assessments in the field.

The American System. This system is much more elaborate than that used in England, and comprises twenty texture groups, with modifying names applicable to each, such as gravelly, stony, or shaly. The definition of profile is ignored in the name and the texture refers to the 'surface soil' only. The twenty textural groups are:

1. C. Sand
2. Sand
3. F. Sand
4. V. F. Sand
5. Loamy C. Sand
6. Loamy Sand
7. Loamy F. Sand
8. Loamy V. F. Sand
9. C. Sandy Loam
10. Sandy Loam
11. F. Sandy Loam
12. V. F. Sandy Loam
13. Loam
14. Silt Loam
15. Sandy Clay Loam
16. Clay Loam
17. Silty Clay Loam
18. Sandy Clay
19. Clay
20. Silty Clay

This system was tried out in England for demonstration purposes some time ago, but was found to be too unwieldy for a country so variable as England. The experienced American surveyor, on the other hand, appears to find little difficulty in its use over the larger and more uniform regions of the U.S.A. The difficulties of definition in either system, however, are in many instances much more apparent than real, because, in normal field work, the variations in texture in any one profile do not extend over so large a range as to include more than two or three grades. Thus, although a surveyor working in a certain region must be familiar with all the grades, it is unlikely that he will find it necessary to use them. Whatever system of textural grading is used the field method for its determination is much the same. A fragment of the soil is moistened, rubbed gently between the thumb and forefinger, and the relative proportions of clay, silt, and sand assessed by the sense of touch, or, as it is usually termed, '*feel*'. Certain soils, especially those of a silty nature, may sometimes be assessed by nibbling a fragment between the front teeth; this gives both texture and 'taste'. As this is a highly sensitive test, however, it may easily be misinterpreted. For field work in general it is always better to work for a time with an experienced field-man to pick up the technique, but when this is impossible the writer has found the following method reasonably successful in the early stages. The student first becomes familiar in the laboratory with the 'feel' of certain well-defined and standard grades. Mechanical analysis figures are studied and a number of soils are selected in which the

two middle fractions add up to about 50 per cent. The 'feel' of these soils is determined, and the modifying influence of more or less clay or more or less coarse material is examined and graded into as many divisions as possible. Modification in 'feel' produced by organic matter, chemical deposits, skeletal material, or stones should also be studied, since these reactions are much more marked in the field than in the laboratory. After some experience a high degree of accuracy may be attained, the American field-men in particular being prepared to classify any grade to within 5 per cent.

Another interesting method for the field classification of texture has been evolved by Krasiuk[1] and is frequently used at the Macaulay Institute for Soil Research. An outline of the scheme, which is self-explanatory, is given on p. 86.

The effect of texture upon the soil profile varies greatly with the type of soil under observation. Indirectly or directly, however, texture affects structure and constitution, and, in consequence, influences aeration, permeability, drainage, and finally root development and penetration. At the same time the physical stability, liability to erosion, creep or slip may also be affected. The more the soil mass is made up of particles of a variety of texture sizes, so is it generally more stable to the effects of erosion. Soils possessing a dominating proportion of one kind of fraction are generally much more susceptible to erosive influences.

[1] A. A. Krasiuk, *Soils and their Investigation in Nature*, 3rd ed. Leningrad. Moscow (Russian).

Mechanical subdivision	*Feel between fingers*	*Appearance under lens*	*Dry state*	*Wet state*	*Rolling between fingers*	*Finer subdivisions*
I. Clays .	Fine homogeneous powder.	Large grains of sand absent.	Very compact—forms crumbs which are very hard.	Very sticky plastic.	Gives long threads.	Acc. to plasticity—(*a*) heavy, (*b*) light.
II. Loams .	Not quite homogeneous powder.	Among clay, sand particles visible.	Compact—crumbly but not so hard.	Plastic.	Gives threads with difficulty and these will not bend into ring.	Acc. to amount of sand: (*a*) heavy, (*b*) medium. (*c*) light. Acc. to size of sand grain: (*a*) coarse sandy, (*b*) fine sandy.
III. Sandy Loams	Heterogeneous Loam alternates with sand (one hor. sand other loam).	Clayey part mixed with sands.	Not uniform in compactness.	Slight plasticity	Threads form with great difficulty.	
IV. Loamy Sands	Sandy particles predominate—small admixture of clay.		Dries into ill-defined crumbs from surface of which sand is easily rubbed.	Cannot be rolled into threads.		Acc. to size of sand grains: (*a*) large grained, (*b*) fine. (*c*) loess-like.
V. Sands .	Consists almost exclusively of sand grains.			Forms a flowing liquid mass.		(*a*) Clayey sands. (*b*) Friable sands .
VI. Gravelly or stony	Together with clayey and sandy particles contains large number of lumps of rock in form of gravel (3–10 mm.) and stones (>10 mm.).		Acc. to amount and composition of fine earth may be clayey, loamy, loamy sand, or sand.			

7. Structure.

Soil structure is an exceedingly interesting phenomenon, and is capable of investigation under two different heads and in two distinct ways.

Soil structure can be studied in the field by the simple exercise of the senses of touch and sight, and descriptions so obtained refer to the soil macro-structure. What cannot be determined in the field because of the extremely small limits of the size of the aggregates and their absolute intricacy with the whole problem of soil life, 'ripeness' and fertility is termed micro-structure. The ultimate *effects* of micro-structure are frequently visible in the field by their effects upon the macro-structure and soil profile generally, but the study of micro-structure itself is still a problem for the pedological chemist or physicist in the laboratory.

Structure, in the field, therefore, is the term defining the cemented aggregates or fragments which may be *seen*, into which the soil mass will crack and break under conditions of the natural drying out of an exposed face, or when a spadeful of the soil is tossed about a metre into the air and allowed to fall into fragments by shock. These fragments are usually termed structural elements and are aggregates of the textural elements held together by colloids. No kind of structure is fortuitous, but is quite characteristic of the colloidal portion of the soil mass and is formed as the result of the operation of certain definite factors. Every soil group and possibly every soil type possesses a specific structure which, under the influence of

a new set of factors, will tend to change into some other equally characteristic type. Structure to some extent obeys the simple laws of crystal formation in that the breaking up of a large cubic aggregate results in the formation of smaller cubic aggregates. Structure is beginning to be recognized as one of the most important properties of the soil mass in that it influences the soil in almost all of its reactions, but especially with regard to aeration, moisture, heat, permeability, and water capacity, and to some extent not fully understood it bears some relation to liability to erosion. For example, a heavy clay soil can, by skilful cultivation, be made to attain a good granular structure and acquire many of the virtues of a good loam due to the increased porosity, drainage, aeration, &c. The creation of one or the other of the Species of the 'Cubic Type' of structure to produce the 'Agronomic Structure' of Sokolovsky is the aim of all rational cultivation. The natural development of structure may be due to various influences in the field which are briefly summarized below, while it may be artificially induced either in the field or in the laboratory by the treatment of the soil with various salt solutions.

I. *Biotic Influence.* The granulation produced by burrowing fauna, such as moles, worms, &c., or by cultivation.

II. *Periodic fluctuation of moisture content* either by atmospheric alternations of wetting and drying or by the rise and fall of the water-table to produce surface friction between the faces of expanding and contracting elements. This latter

is peculiarly noticeable in gley horizons of soils of the heavy clay type.

III. *Destructive Leaching.* The loss of exchangeable bases brought about by humus degradation and destruction of colloidality by exposure, excessive oxidation, and subsequent leaching.

IV. *Root Pressure.* Root development is frequently responsible for some changes in the shape and size of structural elements, though in the writer's opinion it is more closely connected with the soil constitution than with structure alone. Some degree of lamination, however, may often be observed under forest where wind vibration causes stresses upon the lateral root systems of large shallow-rooted trees. Podsols frequently exhibit lamination in the A horizon, but this is probably due to the method of decomposition of the humus and to its reaction on the mineral mass.

V. *True Pressure.* True pressure is the natural pressure of the soil itself due partly to its own weight and partly to the expansion and contraction of colloids by variation in moisture content. Such phenomena may in rare cases be responsible for the degradation of a granular structure to produce a tighter clod structure, though it may generally be assumed that true pressure is advantageous to granulation.

VI. *Unnatural Pressure.* Unnatural pressure as it affects soil structure in the field is mainly concerned with man's careless usage of soil by heavy implements or by too violent operations during

cultivation. The effects most frequently resulting from such treatment is a general loss in 'heart' or 'ripeness'. This is primarily produced through the destruction of the tilth or agronomic structure by packing and reduction of pore space. Then follows the typical agricultural pan with its impeded aeration and drainage. Whatever economic value may accrue from the use of heavy machinery it can only be temporary, because there is undoubtedly a detrimental effect which is cumulative and which has not yet been sufficiently investigated to influence the recent craze for heavy mechanization of small and intensively utilized areas.

Unnatural pressure invariably exerts a deleterious effect upon the size and shape of structural elements as well as upon their consistence or constitution, so that the observer should find little difficulty in diagnosing it in the field.

VII. *Coagulation of Colloids*. Coagulation of the soil colloidal material may be produced either by the reactions of electrolytes, dehydration, freezing, or by the reactions of oppositely charged colloids.

The presence or absence of electrolytes in any particular soil horizon or zone is frequently manifested by the shapes of the structural aggregates. Under certain conditions soils which contain excessive quantities of alkali and also soils which are excessively leached frequently exhibit no definite forms of aggregation at all, in which case they are usually described as being 'structureless'. Soils low in colloid content, which

even under the influence of coagulating factors do not bind into definite aggregates, are frequently referred to as being of 'single grain structure'.

Structural Features. Structural features belong to one or other of two main classes. The first occurs in what may be called (for want of a better term) the surface soil. This surface soil structure is primarily developed under the influence of vegetation, fauna, and the direct effects of climate. The second class occurs in what may be termed the subsoil, and, while it is usually insulated from the direct effects of the atmospheric climate and the surface fauna, it is frequently affected by vegetation, and is always influenced by the soil transpiration current[1] and the percolation stream. The progressive increase in size of the structural elements with depth that is found to be characteristic of Brown Forest Soils is probably due to the diminution of humus down the profile and to the presence of a more highly basic ground-water.

Causes of Special Shapes. The foregoing description of the factors which govern structure development is fairly well known, but little or nothing is known as to the causes for the specific shapes produced in the different soil types, though a line of investigation has recently been undertaken by E. W. Russell into the binding forces of clay particles.[2]

From a study of the measurements of the shrinkage of naturally moist structural elements the writer

[1] G. R. Clarke, 'Brown Forest Soils of England,' *Forestry*, vol. vii, no. 1, p. 43.

[2] 'The Binding Forces between Clay Particles in a Soil Crumb,' E. W. Russell, *Trans. 3rd Internat. Cong. of Soil Science*, vol. i.

believes that there is some definite orientation of the ultimate soil particles in a soil mass which produces a form of cleavage plane along which the elements tend to separate. If fresh well-shaped elements of the prism type or column-like type are allowed to dry out naturally, it is found that there is a greater proportional shrinkage along the parallels of the major axis than along the parallels of either of the minor axes. Also, if and when columnar and column-like structures disintegrate, they invariably fracture along the parallels of the horizontal axes to produce first jointed columns, then prisms, finally to become stable as cubes. The separation of the joints of the columns to form the cubes is explicable by the fact that the main expansion and contraction being along the vertical axis will cause an upward and downward motion of the element to produce friction against its lateral neighbours. Such spaces as exist between the elements will be closed up more quickly through the expansion of the vertical faces by the percolating water than will the rest of the faces of the element, so that a strain will be exerted whereby the element is attempting to expand laterally but is locked by friction. The result is a 'lift' which cracks the element along the parallels of the minor or horizontal axes.

If a certain humus content and base status can be responsible for a certain orientation of ultimate particles it should be possible, by changing this base status and colloidal binding power by leaching or re-grading of the soil mass, to change the shape and size of the structural elements. This is in fact the case and can be observed both in the laboratory and in the field.

The experiments of Sokolovsky,[1] wherein he changes a granular chernozem first into a tenacious and puddled sodium soil and then back again to a granular calcium soil, is a good example of laboratory technique. Field observations of the reclamation of a salt marsh to a neutral grassland (i.e. a sodium clay to a calcium clay) show that the process is not rapid, but proceeds firstly by a degradation of column-like structure to jointed columnar, then to a somewhat spheroidal cube (rounded edges and corners), and finally to the true cube to produce a granular surface soil with a nutty subsoil. The stability of cube type is probably due to the fact that the shrinkage takes place evenly along all parallels, and this must be brought about by the re-orientation of some of the particles to produce a neutralizing effect. The development and alteration of the plate-like type of structure, apart from podsols, being almost specific to certain saline soils of arid climates, obeys the same general laws of friction lift and consequent fracture, though these movements are productive of very different results. The alkaline subsoil clays of Burma, for example, are responsible for the warping and cracking of buildings consequent upon the buckling of the substrata during the expansion and contraction of the clay under varying conditions of moisture content. In some recent work with the writer in the Soil Science Laboratory, Oxford, D. Wooltorton of the P.W.D. Burma[2] found the shrinkage of natural elements of sodium clays differed quite definitely from the shrinkage of normal calcium clays.

[1] *The Problem of Soil Structure*, Moscow, U.S.S.R., 1933.
[2] Private communication. Report to Burma P.W.D. pending.

Description of Aggregates

There are three general methods which are available for the description of the soil aggregates and they must be discussed at some length. The earliest and probably the most systematic method is that evolved by the Russian pedologist Zakharov[1] which confines the description of the *structure* strictly to the *size* and *shape* of the aggregates, the *consistence* or the *tenacity* of the aggregates being described as a separate item.[2]

The logical simplicity of the Russian system is shown in Table II. There are three *types* of structural elements classified according to the *main shape* of the aggregates. The *types* are then further divided into nine *kinds* according to the clarity of definition of the *faces* and *edges* of the elements, and then these are further subdivided into numerous *varieties* according to the *size* of the elements.

The second system which is in use in many parts of the world has been evolved by the American Soil Survey Association. This system makes use of some two dozen categorical names which, though descriptive of the properties of the soil aggregates, may or may not embrace a description of both the *structure* and *consistence* in one comprehensive term. Such a method, though useful, presents serious difficulties, since there appears to be no definite system of reasoning as to when *consistence* should be described separ-

[1] Russian Pedological Investigations, No. 2, 1927.

[2] At the present time the English Soil Survey Conference does not use any definite system for the classification of structure and any terms are used which the field-man thinks suitable for the case, though in Scotland the Russian system is followed fairly closely.

ately or when it should be included in the structural name. For instance, the American terms 'crumb', 'granular', and 'nutty' refer to aggregates of approximately the same size and shape, but 'crumb' is 'porous', 'granular' is of 'medium consistence', and 'nutty' is 'compact hard'. It follows from these examples that a field-man can only learn this particular technique from personal tuition in the field by an already experienced worker. A self-taught field-man might go very far astray by reading and working out the scheme for himself. The American System is outlined in Table III in such a manner as to give a rough idea of the Russian equivalent in the last column. It may be seen from an examination of the two systems that, though each has its good points, neither completely fulfils all the demands made by the modern soil investigator.

The third system of description, which is an attempt to elucidate some of the problems in structure classification, has been evolved by the author at the request of various English workers at home and abroad who have pointed out various difficulties in interpreting the American and Russian systems for their own particular needs.

The Oxford system of classification is outlined in Table IV, and it will be seen at once that it is a modification of both the Russian and American systems. Despite the scientific training of the English-speaking field-man, he usually thinks in terms of feet and inches before converting his measurements into metric units. It is generally much easier for him to visualize a quarter of an inch than its corresponding

TABLE II

RUSSIAN SYSTEM OF STRUCTURE CLASSIFICATION

(A. ZAKHAROV)

Revised translation by A. MUIR

Type	*Kind*	*Varieties*	*Dimensions*
I. Cube-like structure—soil fragments equally developed along the three axes.	A. Faces and edges feebly manifested, soil aggregates mostly complex and irregular in shape.		
	1. Clod structure	Large Cloddy	$>$ 10 cm.
		Small cloddy	10– 5
	2. Crumb structure	Large crumbs	5– 3
		Med. crumbs	3– 1
		Small crumbs	1– 0·5
		Pulverescent	$<$ 0·5
	B. Faces and edges more or less clearly manifested, aggregates well defined.		
	3. Nutty structure	Cuboid	$>$ 20 mm.
		Large nutty	20–10
		Med. ,,	10– 7
		Small ,,	7– 5
	4. Granular structure	Large granular	5– 3
		Med. ,,	3– 1
		Small ,, (powder-like)	1– 0·5
II. Prism-like structure—soil fragments predominantly developed along the vertical axis.	A. Faces and edges indistinctly manifested, aggregates complex and unclearly defined.		Length of vertical axis and cross section diameter.
	5. Column-like structure	Large columns	$>$ 5 cm.
		Med. columns	5– 3
		Small columns	$<$ 3

	B. Faces and edges distinctly manifested, aggregates more or less well defined.		
	6. Prismatic structure, with uniform, even often shining, surfaces and sharp edges	Large prisms	$>$ 5 cm.
		Prismatic	5–3
		Small prisms	$<$ 3
		Prismatic pencil-shaped (more than 5 cm. in length)	1
	7. Columnar structure—the upper basis ('top') rounded and the lower one flat	Large columns	$>$ 5
		Columnar	5–3
		Small columns	$<$ 3
			Thickness
III. Plate-like structure—soil aggregates predominantly developed along the two horizontal axes.	8. Platy structure — horizontal 'planes of cleavage' more or less developed	Schistose	$>$ 5 cm.
		Platy	5–3
		Laminar	3–1
		Foliated	$<$ 1
	9. Squamose structure—horizontal faces comparatively small, partly curved	Shelly	$>$ 3
		Coarsely squamose	3–1
		Finely squamose	$<$ 1

Note. Large column-like fragments are sometimes called pedestals.

TABLE III

OUTLINE OF AMERICAN CLASSIFICATION OF STRUCTURE[1]

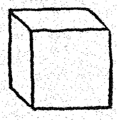
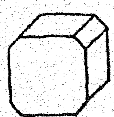
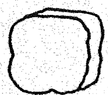
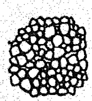
Name	*Shape*	*Size*	*Consistence*	*Russian 'Kind'*
Adobe	Cubic Blocks	20–50 cm.	Not defined	Large clods to nutty
C. Cloddy	Irregular and Angular	>20	Hard	
F. Cloddy		8–20		
C. Lumpy		6–10	Medium to hard	
Lumpy		3– 6		
F. Lumpy		2– 3		
Nutty	Roughly rounded	0·4– 5	Compact to hard	Nutty to granular
C. Granular	Sub-angular	<2 cm.	Medium	
F. Granular		<5 mm.		
C. Crumb	Roughly rounded	2 cm.	Porous	
F. Crumb		<5 mm.		
Mealy		<5 mm.	Soft	
Buckshot	Roughly spherical	2–3 mm.	Hard	Pulverescent
Columnar	Vertical cleavage Horizontal cracks Vertical axis > horizontal axis	Not defined	Not defined	Column-like Prismatic and Columnar
Prismatic columns	Columns broken into regular sections	,,	,,	
Jointed columns	Columns broken into regular sections where vertical axis = horizontal axis	,,	,,	
Platy	Thin plates parallel to surface	1–5 mm.	Med. to hard	Platy
Laminated		<1 mm.	Med. to soft	

Amorphous	Structureless. Uniform arrangement too small to describe.
Massive	No definite structure.
Puddled	No definite structure. Massive structures degraded or deflocculated.
Single-grained	No definite arrangement (as particles in a coarse sand).
Structureless	No definite arrangement.
Crust	Surface effect. Horizon coheres in a crust distinct from lower horizon.
Fluffy	Surface effect. Aggregates *loose*, light and of fine texture.
Floury	Surface effect. Aggregates *loose*, light and of fine texture.
Pulverent	Crumb or Grain produced from massive structure.
Honeycomb	Network of regular sided elements separated by hair-like cracks.
Reticulated	Network of regular sided elements separated by hair-like cracks.

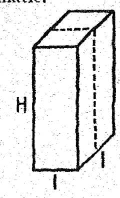
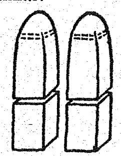
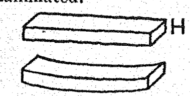
[1] American Soil Survey Association, Bull. 9, 1928.

TABLE IV

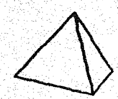
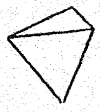
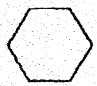
OXFORD SYSTEM OF SOIL STRUCTURE CLASSIFICATION

General Appearance	*Appearance Definition*	*Name*	*Sizes* English	*Sizes* Metric
Cubic. 	Well-defined Cubes.	Large Cubic Med. ,, Small ,,	>6 in. 6–2 in. 2–1 ,,	>15 cm. 15–5 cm. 5–2·5 cm.
	Ill-defined Cubes. Angular (A) Rounded (R) Concoidal fragments	Large (A or R) Cloddy Med. ,, ,, Small ,, ,, Large Starchy Small ,,	>6 in. 6–2 in. 2–1 ,, $>\frac{3}{4}$ in. $<\frac{3}{4}$,,	>15 cm. 15–5 cm. 5–2·5 cm. >2 cm. <2 ,,
	Roughly rounded *solids*.	Large Nutty (Walnut) Med. ,, (Filbert) Small ,, (Peanut) Gunshot Large granular Small ,,	1 in. $1-\frac{1}{2}$ in. $\frac{1}{2}-\frac{1}{4}$,, $\frac{1}{4}-\frac{1}{8}$,, $\frac{1}{8}-\frac{1}{16}$,, $<\frac{1}{16}$,,	25 mm. 25–12 mm. 12– 6 ,, 6– 3 ,, 3– 1 ,, <1 ,,
	Roughly rounded *aggregated* small particles.	Large Crumb Med. ,, Small ,, Crumb Dust	$\frac{3}{8}-\frac{1}{4}$ in. $\frac{1}{4}-\frac{1}{8}$,, $\frac{1}{8}-\frac{1}{16}$,, $<\frac{1}{16}$,,	9–6 ,, 6–3 ,, 3–1 ,, <1 mm.

OXFORD SYSTEM OF SOIL STRUCTURE CLASSIFICATION (*continued*)

General Appearance	*Appearance Definition*	*Name*	*Sizes* English	*Sizes* Metric
Prismatic. 	Well-defined Prisms.	Large Prismatic	$>2\times2\times$ Height in.	$>5\times5\times$ H cm.
		Med. ,,	$2\times2\times$ H– $1\times1\times$ H	$5\times5\times$ H– $2{\cdot}5\times2{\cdot}5\times$ H cm.
		Small ,,	$<1\times1\times$ H	$<2{\cdot}5\times2{\cdot}5\times$ H.
Columnar. 	Well-defined Prisms with *indefinite tops*, i.e. Columnar.	Large Columnar	,,	,,
		Med. ,,	,,	,,
		Small ,,	,,	,,
	Jointed Columns. Series of Prisms, usually massive with *wide* vertical cracks and narrow horizontal cracks.	Large *Jointed* Columnar	,,	,,
		Med. ,, ,,	,,	,,
		Small ,, ,,	,,	,,
			State height of column and cross-section at top and base.	
Laminated. 	Plates (flat).	Slabby	$>\frac{1}{2}$ in. H.	
		Platy	$>\frac{1}{8}$,,	>3 mm.
		Foliated	$<\frac{1}{8}$,,	<3 ,,
	Scales Curved (saucer-like)	Scaly	$>\frac{1}{8}$,,	>3 mm.
		Flaky	$<\frac{1}{8}$,,	>3 ,,

In addition to the systematic classification of the main types of structural elements, certain soils may be found wherein aggregates occur which do not readily allow of such simple description, and a further group is needed. Such a group may be termed Polyhedral.

	Pyramidal (Tetrahedra).	Large=Pyramids Med. ,, Small ,, Very small ,,	$>$6 in. sides 6–2 in. 2–1 ,, $<$1 in.	$>$15 cm. 15–5 cm. 5–2·5 cm. $<$2.5 cm.
	Inverted Pyramidal.	,,	,,	,,
	Soils of meadow clays and strong clay zones.			
	Polyhedral. State number of faces.	Large Polyhedrons Med. ,, Small ,,	$>$1 in. 1–$\frac{1}{2}$ in. $<\frac{1}{2}$ in.	$>$25 mm. 25–12 mm. $<$12 mm.

Six-sided aggregates are common in tropical soils, but, occasionally, elements may be found with a greater number of faces, but these need not be confused as variations of the Cubic. These are entirely different.

Single grained or Structureless.	Defined generally by 'feel'.	Single grained Mealy (Sharp sand with hydrated sesquioxides) Powdery Desert Dust } generally tropical types Volcanic Dust	2–1 mm. 1–0·2 mm. $<$0·2 mm.

6 millimetres. For this purpose sizes are graded primarily into English units and their nearest metric equivalents are given as a secondary item. The nomenclature differs from the Russian system in many important details, so that the names of particular shapes are much more in keeping with their general appearance; for example, the name 'nutty' applies to something which resembles a nut (i.e. it is rounded). In other respects, too, an effort is made to describe some of the peculiar shapes commonly found in English and tropical soils not catered for in either of the other systems. The structure of tropical soils is often the result of the intense weathering and the removal of the more soluble material to leave a more resistant mineral skeleton, e.g. the gun-shot structure and cellular consistence of murram.

Some Typical Structures to be found in Various Soils

Temperate Maritime Soils.

Brown Forest Soils. The Upper Horizon. This possesses the granular structure of the Russian system or the crumb structure of the American description, the size and tenacity of which depend chiefly upon the dispersion or coagulation of the humus colloids by calcium. This horizon 'gradually merges' into the

Second horizon, which is characterized by a lower humus binding power producing small cloddy or 'starchy' to small prismatic elements increasing in size with depth, which may in cases of ground-water influence change with a 'clearly defined' horizon to

The Gley, which has a 'cuneiform wedge' (pyra-

midal) structure wherein the elements resemble triangular prisms resting on one long face with one edge upward. The faces and edges of each element are characterized by a blue burnish produced by lift friction.

Meadow Soils. Upper horizon—consists of typical 'sod' formation characterized by block structure and clearly defined horizons merging into the

Second horizon of large columnar or large prismatic elements, in the faces of which may be found concretionary ochres and manganese. This gradually merges into the Gley.

Rendzinas (Brown and Black Calcareous Soils). Upper horizon—characteristic granular structure, the size of the elements depending entirely upon the calcium-humus content. This merges very gradually through the

A–C horizon, which is usually coarse granular to 'large crumb', increasing in size with increasing depth. This horizon exhibits the properties of a mean of those of the A and C horizons, the dominating influence of which increases with the proximity to the major horizons.

Insubrische Soils of the Tessin (Palmann). [Terra Rossa or Mediterranean Type.] The A horizon is medium crumb, gradually merging into the B horizon which is mainly large crumb, the size of the aggregates increasing to small nutty at depth.

Continental Climate. Russia or North America.

Loamy Chernozem. Upper horizon (Russian system)—granular to fine powdery.

Lower horizons—nutty, increasing in size with depth to prismatic.

Solonetz (Columnar Alkali or Black Alkali). (Gemmerling.) The upper layer may be structureless or dust-like but sometimes may be foliated.

The second layer is the *characteristic* one, composed of true columns with rounded tops (7 cm. diam. and 10 cm. high).

The lower layers are nutty and finely prismatic.

Russian Grey Forest Steppe (Tiurin). The upper layer is granular to granular-nutty.

The second layer is nutty with the *characteristic* well-defined silica flour on the aggregates.

The third layer is prismatic nutty.

The fourth is prismatic.

The chief characteristic is the complete lack of granulation.

Tropical Zone Soils

Though there is some degree of structural development in most tropical soils they are, in the main, more readily characterized by their constitution. They may, however, be roughly classified into two large groups:

I. Those soils through which water percolates easily to a great depth and from which the moisture is removed mainly by drainage. Such soils are generally red or yellow.

II. Those soils through which water does not readily percolate and from which the moisture is removed mainly by evaporation. Such soils are generally black or dark.

Because of the tendency for the retention or accumulation of salts by this second group, structural features are generally more clearly developed in these soils than in the first group of the red and yellow soils.

Red and Yellow Soils.

Red Tropical Rain Forest (Campbell). Generally structureless.

Tropical Yellow Earth (Campbell). Upper layer single grained, which under the influence of consistence becomes faintly crumb or cloddy with depth.

Red Ilepa Soils of Nigeria (Doyne). Upper layers single grained to small cloddy, modified by iron concretions, gradually merging to lower layers containing polyhedral aggregates which increase in size with depth.

Red (*Gardud*) *Soils of Sudan* (Morison). Upper layers powdery to small gunshot, frequently modified by concretions to produce an impression of 'structure' which is not entirely due to structural elements. Lower layers contain elements increasing in size with depth to small clods.

Black (*Badob*) *Soils of Sudan* (Morison). Upper layers—block or large clods which *decrease* in size with depth to develop distinct foliation in and around the calcium-concretion accumulation zone.

Black Tropical Rain Forest (Campbell). Upper layer well-defined gunshot merging at depth to nutty. Structure and depth of humus penetration closely related.

Cohesion of Structural Aggregates

In addition to their specific size and shape, structural elements also possess a certain power of resistance to further disintegration. This power of resistance is closely related to the proportion of organic and mineral colloids present and to their degree of hydration. Schloesing estimates that the binding power of the humus colloid compared to that of the mineral or clay colloid is in the proportion of about eleven to one. For this reason the A_2 zone of a sandy podol when thrown into water becomes completely disintegrated, whereas the A_1 zone of the same soil will not completely disintegrate even when boiled with water; but if the colloids are first dispersed by an alkali disintegration occurs immediately. The degree of moisture present in the colloids of saline or alkali clay soils is responsible for their being exceedingly tough when wet, but becoming workable at a special moisture content, and then again becoming unworkable as clod or dust soils on complete drying. Clay soils of low humus content are generally reasonably workable when moist, but are cloddy and almost unworkable when dry. Such characteristics are detectable in the field and are capable of a certain classification. The American fieldmen deal with this characteristic under the heading of Soil Consistence (see p. 109).

8. Soil Constitution (*of the Russian Soil Survey*).

The Russian pedologists use the term 'Soil Constitution' to describe the properties of the soil mass in regard to its 'Porosity' and its 'Compactness'.

Porosity is partly correlated with soil structure and is a property which may be *seen* in the examination of the soil profile.

Compactness, on the other hand, is a property which may be *felt*, either during the digging operations in the soil mass or by the handling of the material in the walls of the freshly exposed soil pit.

Porosity is dependent upon the size, shape, and quantity of the *air spaces* as cavities or cracks *in* and *around* the soil aggregates of the whole soil mass and is classified under two heads:

A. The nature of the cavities *within* the whole soil mass, including the internal structure of the aggregates.

B. The nature of the cavities *between* the structural aggregates.

A. I.	Fine Porous cavities	1 mm.	diam.	as in degraded B.F.S. A horizon.
II.	Porous	,, 1–3 ,,	,,	Podsol and Loess.
III.	Spongy	,, 3–5 ,,	,,	Podsols and B.F.S. (A_1) zone.
IV.	Cavernous	,, 5–10 ,,	,,	Biotic influence.
V.	Cellular	,, 10 ,,	,,	Lateritic Soils.
B. I.	Fine Fissured	,, 3 mm.		Usually vertical.
II.	Fissured	,, 3–10 ,,		Prismatic and Columnar soils.
III.	Clefts	10 ,,		Alkali soils, Heavy clay and meadow in dry weather.

Compactness is easily determined by the feel of the spade during digging operations.

I. Very Compact. A spade will *not* enter; a pick or bar is needed. (Some prismatic

zones of the alkali soils and particularly the second layer of the salines. Certain soils with hardpan layers.)

II. Compact. Soil fragments are very close together and a spade will only enter with difficulty. (B horizon B.F.S. and certain Podsols.)

III. Loose. Separate soil particles. Shovel enters easily and a sod falls readily to pieces. (Rendzinas and many of the Tropical Loams.)

IV. Crumbling. No cementation of the soil mass and little or no structure. Sandy soils and sometimes calcium saturated soils of high organic content.

When taking notes of soil 'constitution' in the field it must be remembered that moisture, humus, new chemical deposits, and also biotic factors may greatly influence these characteristics, and any information obtainable is recorded under the heading of 'Special Characteristics'.

The foregoing Russian system of classification of constitution has much in common with the American methods in the description of soil 'consistence' and 'porosity'.

Consistence is the term used to denote the degree of cohesion of the soil mass and its resistance to the breaking up of structural aggregates mainly under handling pressures.

Porosity is used in exactly the same sense as it is used by the Russians (i.e. volume of air space). The following list of technical terms and their interpretation explains itself.

Outline of the American Method of Classifying Consistence

Name	
Brittle.	Dry soil breaks with clean sharp fracture.
Cellular.	Pore spaces of regular size throughout soil mass.
Cemented.	Soil aggregates bound together by a cementing agent.
Cheesy.	Characteristic of a *wet* soil. Elastic, bends without fracture.
Coherent.	Compact. Very compacted.
Compact.	Dense and firm without cementation.
Firm.	Moderately hard, fragments can be broken between fingers.
Friable.	Easily broken, and reduced to crumb structure. (Good agricultural tilth.)
Hard.	Very difficult to crush between fingers only.
Impervious.	Very resistant to water or root penetration.
Loose.	Soil of small aggregates and maximum pore-space.
Mellow.	Porous mass, softer than friable, no tendency to pack. (Good agricultural tilth.)
Porous.	Same as Russian.
Plastic.	Readily moulded.
Soft.	Readily crushed between fingers.
Sticky.	Adhesive when wet, cohesive when dry.
Tenacious.	Very like sticky but applies more to a cohesive character when wet.
Tight.	Compact, impervious and tenacious, usually plastic.
Tough.	Bores easily but very difficult to break.

Since the American method for the description of soil consistence aims at a literal interpretation of the observed facts, it works well in the field and the surveyor finds but little difficulty in learning the technique. Since, also, the terms may be applied both to the material picked up on the auger or to that dug out with a spade, it fulfils all the requirements for the English worker and can, therefore, be safely recommended for English Soil Survey purposes.

9. THE MINERAL SKELETON (Nature of Stones, &c.).

This item, though of very great importance in the field, is rarely considered at all in the laboratory examination of a soil sample (other than as a soil monolith), because in the process of the preparation of the sample for analysis the stones cease to exert any measurable influence. It is important therefore that fairly full notes should be taken in the field. The absence, or presence, quantity and distribution throughout the soil mass, of the unweathered, or partially weathered, mineral material greater than 2 mm. diam. must be recorded, since the soil characteristics may be considerably affected by varying quantities of such material. These materials can conveniently be described as 'stones' and can be classified under two main headings according to:

I. Chemical nature. II. Shape and Size.

I. *Chemical nature.*

(*a*) Residual Parent Material or adventitious material which is *capable* of further weathering and

comminution to produce 'fine earth'. Such material may produce both chemical and physical effects upon the soil-forming processes and is a characteristic of immature soils. Stones of this nature usually consist of carbonates of lime and magnesia or the more complex silicates and alumino-silicates discussed under 'Parent Material'.

(*b*) Residual or adventitious materials *incapable* of further chemical decomposition so long as present conditions prevail. They may, however, be subjected to further comminution, but their only direct effect upon the soil mass is a physical one. Such materials as quartzite pebbles and flints may be included in this category.

(*c*) Concretionary materials which, through chemical or physico-chemical reactions, have accumulated in the soil mass, though not usually referred to as 'stones', do in fact frequently behave as such. Their description and properties are, however, more properly dealt with under 'New Chemical Deposits' (see page 115).

The recognition of the constituents of either of the above categories is merely a matter of the examination of a hand specimen and possibly of its fracture after a blow with a hammer.

II. *Shape and Size.*

Shape may be divided into four kinds:

(*a*) Angular (including cubic and flat varieties).
(*b*) Sub-angular (including cubic and flat varieties).
(*c*) Rounded (including nodular formations).
(*d*) Shales.

Size. The length in inches or millimetres of the *major* axis is always understood to be taken unless otherwise stated.

Name	*English inches*	*Metric mm.*
Gravel	$\frac{1}{8}$–$\frac{1}{4}$	2–5
Coarse Gravel . . .	$\frac{1}{4}$–$\frac{1}{2}$	5–10
Very small stones . .	$\frac{1}{2}$–$\frac{3}{4}$	10–15
Small stones . . .	$\frac{3}{4}$–1	15–25
Medium stones . . .	1–2	25–50
Large medium stones . .	2–4	50–100
Large stones . . .	4–8	100–200
Very large stones and boulders	> 8	> 200

It is only necessary to judge the sizes by eye so that the apparent discrepancy between English and metric units is not of very great importance.

It is thus possible to describe a stony soil as containing 'sub-angular, coarse gravel', or 'rounded, large medium stones', &c.

Quantity.

The quantity of stones present may be recorded under one of the following headings:

I. Stoneless or nearly so.

II. Few (where the visible effect upon the soil mass and its utilization is negligible).

III. Frequent (some visible effects noticeable both in soil mass and sufficient to affect certain systems of utilization).

IV. Dominant (an impression of 'more stones than soil').

The general effects produced by stones in the soil mass depend to a great extent upon their nature,

quantity, and distribution. For example, a generous proportion of stones on the surface of the soil may act as a mulch and tend to prevent losses by evaporation; excessive stoniness, on the other hand, will tend to produce a too loose constitution and allow of an excessive percolation. In arable practice, too, many stones will reduce the effective area of the soil available for the plant population. Local or micro-leaching may occur in soil with excessive quantities of stones of acid rocks to produce a degradation which would not otherwise occur: frequent examples of this action are to be found among the flint and silicious gravel soils of England. If, however, the stones are derived from calcareous rocks, the tendency towards degradation becomes greatly reduced owing to the maintenance of the base status by solution of the basic material, such actions resulting in the production of the Rendzinas and Red and Brown calcareous soils of the temperate zones.

The distribution or the position of the stones in the soil mass may have a marked effect upon the utilization of the site, in that a layer of gravel in the 'subsoil' of a clay soil may be sufficient to allow of efficient drainage and economic utilization which could not otherwise occur. A clay 'subsoil' under a gravelly surface layer, on the other hand, may produce an imperfect drainage profile of little utilization value.

10. Special Characteristics.

Under this heading will be included all the information obtained from the study of the sub-horizons or

zones which cannot readily be tabulated under the broader description of the main horizons. Such information differs from all that which has been obtained previously in that one-word answers are not generally possible. For example, under the heading 'Carbonates or none' in item (4) a plus or minus sign is sufficient, but in the 'special' notes the nature, size, shape, &c., of any material would have to be entered.

Special Characteristics are noted in the following order:

Degree of Moisture.
Chemical Deposits.
Acidity as pH.
Drainage characteristics.
Root Penetration and effects of Fauna.

Moisture.

For most purposes the terms *dry*, *moist*, and *wet* should be used in a comparative sense. A soil might be described, for example, as exhibiting a moist upper zone, a drier middle zone, and a wet lower zone, though of course the nature of the weather immediately preceding the examination must be borne in mind while taking notes. The manner and the direction in which the water tends to move is of the greatest importance in the study of the drainage characteristics of the profile.

Chemical Deposits of true Pedological Origin.

Most new growths of chemical deposits are due to reactions involving the soil water and are mainly

of a precipitative nature. They are recognized and classified in the field according to their form and colour.

Efflorescences. These occur on the outer edges and rough surfaces of drying out structural elements. They are extremely finely divided, sometimes resembling a dusty powder and occasionally existing as a bunch of very fine hairs or bloom.

Dendrites. This term is used when efflorescences occur on the faces of the elements or upon stones to give the impression of a picture of a tree or branching plant. Such designs are frequently produced by manganese in certain of the Brown Forest Soils.

Crusts. These represent a greater development of the efflorescences in thickness and distribution, but usually they occur as a surface deposit by the drying out of a concentrated soil transpiration current. Extreme examples of crust formation exist in the crusty alkali soils.

Veins and Tubes. These are usually well defined as the fillings of old root channels and are frequently to be found in heavy soils under either woodland or meadow conditions. Petrified, fixed, or filled animal burrows and worm-holes may sometimes be included.

Concretions. Concretions usually occur as extensive zones of grain-like and nodular accumulations and are especially noticeable in the 'murram' of the tropics or in the lower zones of the Black Earths of Russia and America, and in the Black Cotton Soils of Africa.

Streaks and Interlayers. Streaks and interlayers

usually occur when the whole of a zone is undergoing induration by the deposition of some cementing agent.

Humus Columns. These occur in very heavy clays where during drought the soil mass cracks into deep clefts. When the rains commence humus falls, or is washed, into the cleft so formed. The subsequent expansion of the clay then seals a column of humus into the soil mass, sometimes to a considerable depth.

Chemical Compounds and the common forms in which they may be found.

(*a*) *Crystals occurring as Efflorescences, Crusts, Interlayers, and Pockets.* Carbonates, chlorides, and sulphates of alkalies, being easily soluble and therefore readily carried in the soil transpiration current, are usually found as fine crystals or crusts in the upper zones. Gypsum is usually of ground-water origin and occurs as 'earth hearts' or twin crystals at various depths in many distinct soil types. Calcium carbonate as calcite or aragonite may be observed in the A–C horizons of certain limestone soils by deposition from solution of skeletal material in the percolation stream.

(*b*) *Amorphous Powders.* In certain soils white powdery deposits of dehydrated silicic acid may be observed as 'flour of silica' and may be distinguished from other white amorphous substances of the soil mass either by means of a drop of indicator, or by its insolubility and tastelessness on the tongue.

(*c*) *Concretions and Deposits of Irreversible Material.* The compounds of iron, alumina, manganese, titanium, and phosphorus occur in a great variety of

colours and forms and a very brief summary only is possible.

Iron and alumina sesquioxides occur as the ortstein layer in the B horizon of podsols. Ferruginous compounds frequently develop as black or brown beans, grains and ore grains, and occur in great variety in humid soils of the temperate and tropical zones. Spots of brown-yellow 'eyes' and brown 'dots' of iron and manganese are common in heavy clay soils with Gley horizons. The lower oxides (protoxides) of iron in association with phosphorus may be found as vivianite in the deeper horizons of swamp soils. Air may oxidize this compound, when efflorescences of a blue bloom appear which may later turn brown.

Other ferruginous deposits occur as brown laminae, brown ochreous or brown and crimson spots and patches. Crimson spots are often to be observed in tropical soils and in the red soil of the Middle Lias Loam, which it is sometimes suggested might be a fossil Tropical Loam.

Red and yellow ochreous nodules, ochreous veins, pseudo-mycelium and rusty patches often occur in the root channels and in interstices of Meadow soils of heavy clay origin.

Dark brown to purple dendrites of manganese-iron are frequently found on the faces of structural elements and stones of the soils wherein oxidation dominates reduction in the Gley zone.

Calcium carbonate as 'white eyes', nodules, or 'puppets' may be found in the lower horizons of certain Szik Soils, Chernozems, and also in Brown Forest Soils of heavy clay origin in which surface run-off exceeds

percolation. Concretions of calcium carbonate coated by a dull varnish of manganese compounds are common in certain of the black soils of the Sudan.

Dark grains of limonite and manganese dioxide and sometimes haematite may be recognized by their streak on rough porcelain.

Haematite	Red	Laterites
Limonite	Brown	Meadow Soils
Red and Yellow Ochres		Meadow Soils and Gleys
Manganese	Black	Meadow Soils and Gleys

(The similarity between the black fragments of manganese and elementary carbon was discussed on p. 80.)

pH Measurement.

The value of this determination depends to a great extent upon its interpretation, and for field work a very rough idea, perhaps to the nearest 0·5 pH, is sufficient. It is valuable to know that one zone is more or less acid than another, and that there is some gradation in the profile, but the absolute values are not so important as a range of comparative figures.

Many field methods of sufficient accuracy are available and the choice must rest upon personal inclination. It must be remembered, however, that, the more sensitive the test, the more treacherous it becomes in the field, owing to difficulties of cleanliness. Perspiring fingers, extraneous dust, and, probably worst of all, the instability of indicators in stoppered bottles, are difficulties for which the field-man must be prepared.

Drainage Characteristics of the Profile.

Since the soil-profile description of drainage only requires the determination of one of the four categories, very little observation is required for its definition beyond that which has already been noted in the study of the texture, constitution, and moisture condition. The chief clue is the evidence of anaerobic ground-water reactions. In an impeded drainage profile there will always appear paler colours of the mineral mass due to reduction and ground-water leaching; mottling may occur, but is not always an essential criterion, since weathering of parent rock often produces a similar effect. In certain soils, the water tables of which have been modified by artificial drainage operations, evidence may be found of two gley horizons. The old or upper gleyed zone will show signs of more recent oxidation or aeration in that brighter colours will be found on the edges and faces of the structural elements, the characteristic blue-green varnish will have disappeared, and the oblique face of the wedge-like structure will have become modified towards the cubic or prismatic type.

The zone of maximum air and moisture fluctuation is usually characterized by mustard-seed grains of manganese concretions and nodular ochres of various colours which will be recorded under the heading of 'chemical deposits', but the observation must be utilized for the diagnosis of the drainage characteristics. Well-drained soils are always well oxidized to full colours. The size and shape of the structural elements, the soil constitution, and the true texture all exert

their specific influences. Another important diagnostic factor is to be observed in the colour of the soil in the immediate vicinity of roots. When the channels of the living roots are picked out in lighter colours than the surrounding soil mass (i.e. a brown soil has its roots outlined in grey or green) it may be taken as the criterion of impeded aeration. The roots needing oxygen must take it from somewhere, and the fully oxidized iron compounds present in the soil mass become reduced. After a few profile pits have been examined and recorded according to the questionnaire their definition becomes obvious.

During a Soil Survey of North Shropshire[1] Davies and Owen made use of six general descriptions for the classification of their soils upon a drainage and vegetation basis. Since the significance of these two items as being interdependent is not sufficiently recognized in ordinary Series mapping, their paper is extremely important. The following is a résumé of their remarks on the subject. They recognize two main groups dependent mainly upon the soil development.

Group I. *Soils developed under conditions of free drainage.*

Such soils belong to the World Groups of Soils, Podsols, Brown Forest Soils, and Brown Earths due to some modification, such as the result of human interference. These are then subdivided into

a. Soils under natural vegetation.

b. ,, ,, cultivated vegetation.

[1] *Soil Survey of North Shropshire*, W. Morley Davies and G. Owen, Oxford University Press, 1934.

Sub-Group I *a* is characterized by podsols carrying *Erica*, *Vaccinium*, &c. There is some doubt as to whether this podsolic condition is primary or is developed as a result of the removal of the primeval forest.

Sub-Group I *b* is characterized by a soil development which may be described as a brown earth (uniform SiO_2/Al_2O_3 ratio throughout profile). This results from the enclosure and cultivation of the natural heath podsol to which it would rapidly revert if the land were to drop out of cultivation.

Group II. *Soils developed under conditions of impeded drainage.*

Such soils belong to the World Group, Meadow Soils.

Sub-Group II *a*. *Natural soils with high water-table.*

Such soils are almost continuously submerged and bear a flora of aquatic plants resulting in the formation of fen peat (developed under anaerobic and neutral conditions).

Sub-Group II *b*. *Drained soils with a natural high water-table.*

These are dominantly organic soils. Their depth depends much upon the length of time during which they have accumulated and the nature of the vegetation. The subsoil is usually bleached, probably due to anaerobic conditions and reduction of iron compounds.

Sub-Group II *c*. *Natural soils with impedance due to impervious layers.*

The primeval associations of these soils were probably one or other of wet woodland with a semi-aquatic ground flora such as *Aira*, *Juncus*, *Carex*, &c., or wet grassland. Since most of the areas once under these associations are now drained they have been converted into soil types of the next sub-group.

Sub-Group II *d*. *Drained soils with impedance due to impermeable layers.*

The effect that artificial drainage has had upon the older associations is incalculable, since some of the low-lying land now under grass was probably dominated at one time by *Scirpus*, *Eriophorum*, *Carex*, &c.

Root Penetration and Effects of Fauna.

Each of these subjects exerts an important influence upon the structure and constitution of the various horizons and in consequence affects both the aeration and drainage.

Roots.

Observation of root development gives clues to changes in soil constitution, moisture conditions, and limits of aeration. For example, when tree roots cease to grow downwards, bend at a sharp angle, and run laterally there is an obvious reason, which it will behove the observer to find out and explain. The condition or nature of the roots, as to whether they are anchor roots, fibrous, old, young, dead, &c., and their

quantities and distribution are all important items of general value and as such should be recorded. In turfy soils the nature of the sod layer is very important, the development of the grass roots being obviously correlated with the quality, population density, &c., of the vegetational cover.

Fauna.

The effects produced by fauna upon the soil mass vary greatly according to the particular species involved and to their geographical distribution. From this point of view fauna may be divided into three great groups, dependent mainly upon their zone of habitation in, or upon, the soil. The three groups comprise:

I. The intra-soil fauna which includes protozoa, worms, insects, &c., which take part in soil-forming processes by living and moving within the soil mass.

II. The extra-soil fauna which include the birds and those animals which eat and sleep upon the surface of the earth and produce little or no movement within the soil mass.

III. Another group comprising those creatures which inhabit a dual environment partially in and partially upon the soil. Such creatures include the burrowing animals such as the rabbit, and numerous insects and/or their larvae. The effects of these upon the soil mass are frequently of extreme importance.

Fauna, generally, may be looked upon as good indicators since, if conditions change so as adversely

to affect their environment, a colony owing to its mobility may migrate or die out with great rapidity. The healthy population of a site by a certain species of fauna may be looked upon as indicative of a condition of harmony and general equilibrium. Man as a species of fauna has been discussed in an earlier chapter, so that for this purpose the term 'fauna' may be confined strictly to the lower forms of animal life. In tropical soils the effects of the fauna are often of the greatest importance in soil development, and though little systematic study of the whole subject has been undertaken, very many close observations in certain localities have been made and carefully recorded. Probably the greatest of all faunal influences are produced by the numerous species of termites. So great are their activities that their nests form the largest animal erections in the world and in certain places, as in Australia and Africa, the population is so great that the number and size of their nests change the shape of the whole country-side and give rise to the 'termite towns' of the travel books. There are three main types of nest to be found, some species building up mounds, while others live mainly beneath the surface; still other species exist which build partly above and partly below the surface. The mound builders may erect structures up to many metres in height or they may be quite small. The bringing up to the surface of the mineral material underneath stimulates aeration and oxidation so that the heaps are generally red even if the soil material was originally grey or yellow. Such material when levelled is usually very fertile. Another type of nest occurs in

which the cementing material resembles papier-maché and is prepared from wood. In tropical rain forests termites are probably mainly responsible for the destruction of the surface organic matter. Vageler estimates that about 100 tons of fresh organic matter per acre falls to the forest floor per annum, and that it does not accumulate is probably due to termite activity. The excretion from such vast numbers of termites brings back to the surface much of the mineral matter from the vegetation they have consumed. In certain areas this mineral material resembles a calcareous cement and is a valuable source of lime in lime-deficient areas. The peculiar habit of the termites for the cultivation of fungus gardens in their nests accumulates a rich content of organic matter not to be found in the surrounding unoccupied land. The effects of termite activity in the tropics has been likened to that of the earthworm in the other climates, but this in fact is not really true. The nature of the material which has passed through the body of the earthworm is entirely different to the secreted material used by the termites in their termitaria. The life-history of the termite is admirably described by Steven Corbett in *Biological Processes in Tropical Soils*, while many general remarks about their habits and activities are given by Blank, in vol. vii of *Bodenlehre*, and by Vageler in *Tropical Soils*.

In the cooler climates of the Brown Forest or similar regions the earthworm, the mole, and the mouse or vole are probably of the greatest importance. The earthworm in particular may be regarded as an extremely valuable 'indicator'. Worms are, in general,

peculiarly sensitive to acidity and are rarely found in conditions of acidity greater than pH 5. Thus much may be learned from their presence or absence. They also act as good indicators of the limits of distribution of humus and air, since they rarely travel lower than is convenient for their needs. For a worm to be found in a true gley horizon is a rare phenomenon and would require some explanation such as a recent lowering in height of the water-table following a new system of drainage conditions. The value of the worm or the mole as soil-forming factors depends to a great extent upon their burrowing, aerating, and draining capacity, while the bringing to the surface as casts or mounds material from below improves the constitution and in certain cases may prevent soil degradation by the re-calcification of the surface horizon.

The black soil of the great grain belts of Russia, &c., owes its characteristic deep black zone to the inwash of surface organic-soil material into the burrows of hibernating animals such as marmots during the melting of the snows.

III

SOIL SAMPLING

Soil Sampling.

In interpreting laboratory data a soil chemist is as much concerned with the local circumstances of the site as with the properties of the actual sample of soil received, so that some sort of site and profile description should always accompany a soil sample. When this site and profile description has been made as fully as possible in the field the taking of samples for further investigation must be carried out along two main lines in order to obtain a fair representation of the soil as a whole. The primary sample is, of course, the profile sample representative of the general pedological processes on the pedological site and of the Soil Series. Secondly, the collection of a sample from the arable layer of the soil, which from field to field, through cultivation and various systems of manuring and utilization, may differ somewhat between themselves, though still belonging to the same Soil Series.

The Profile Sample.

The taking of the soil sample as a soil monolith for a permanent record of the soil character is in the end the most satisfactory method to adopt, although if this is impracticable the carton method described below may be used. The advantages of the monolith sample often outweigh the disadvantages of the labour involved in its collection, by the preservation of the structure and constitution; at the same time, too, it

is often easier to pick out horizonal differences when the sample is laid out on a well-lit bench than when the observer is cramped up against the side of a hole often under variegated light filtering through vegetation. The method of procedure described below is now coming into general use by soil workers both at home and abroad.

For sampling purposes a 5-inch monolith is taken instead of the usual 4-inch exhibition specimen, and the telescopic lid is fitted at its maximum capacity for conveyance to the laboratory. It is then faced to the 4-inch (exhibition) limit by the careful picking out of the structural elements, so that fair samples of each horizon are obtained. These are weighed and stones and fine earth are determined in the ordinary manner.

The soil sample container is made of steel, and is 26 inches long. Profiles to any depth may be taken, however, as containers are made to dovetail into each other. Sections may be taken separately in the field, and complete profiles may be built up from these in the laboratory without any serious disturbance of the natural soil structure. The advantage of the short sectional container is that each section, when full, is approximately a one-man load. The following is a description of the equipment and the method of using it.

A complete unit consists of container, lid, ends, envelope, slice, and bottom clip, the specification of each of which is given below.

Container.

An open-ended trough, $26 \times 8 \times 4$ inches, of 20-gauge mild steel, accurately bent so that it is $\frac{1}{8}$ inch

wider at one end than the other (see Fig. 8). Holes for nails are accurately spaced near the ends to fix wooden end pieces and to coincide with holes in the lid. The taper allows for telescoping when composite profiles are built up from two or more containers.

Lid.

The lid is made of the same material as the container. It is $\frac{1}{8}$ inch wider at each end than the container, over which it fits accurately. The sides are 2 inches deep and have seven closely spaced nail holes at the ends. This arrangement enables monoliths to be taken up to 1 inch thicker than the 4 inches of the container.

Ends.

These are of straight-grained soft wood to fit the different-sized ends of the container, and 5 inches in depth. The grain runs longitudinally so that shavings may be pared off in the field to make accurate fitting of the lid.

Envelope.[1]

This is purely a sampling tool of heavier gauge, made to fit flush over the container in order to take the extra inch of soil not obtainable by the 4-inch container. It is not required if no extra soil is to be taken. Nails may be fixed through the envelope and container to hold the bottom clip in position and so prevent the soil slipping from the bottom of the monolith.

[1] Not absolutely essential but useful when transport of implements, &c., is only of secondary or negligible importance.

Slice.

A piece of strong sheet steel or a flat spade blade to sever the soil at the base of the monolith.

Bottom Clip.[1]

A piece of folded steel, shaped to fit over the lower end of the container and temporarily secured by two nails pushed through holes in the sides, and into the soil in the container. This clip prevents the sample from slipping out of the container during the process of lifting from the profile pit.

Method of Collection.

The operation requires two men for complete success. A site being chosen, the hole is dug and faced up ready for the container. The container (or the container in its envelope) is then pressed firmly against the profile with its wider and upward end 1 inch above the soil surface. Two methods of cutting back may now be used according to the texture and consistency of the soil. With stony, light, and friable soils cuts are made as in Fig. 4.

The first cuts A–A are made with a 12-inch knife or a coarse-set pad saw reversed in its handle to give a draw cut (the latter is the more efficient). A steady pressure is applied to the container so that it inserts itself into the cuts, but it is rarely possible to push the container right home. Cuts *B–B* (Fig. 5) are then made by chopping back with an adze some 3 or 4 inches outside the cuts *A–A*. Pressure on the con-

[1] Not absolutely essential but useful when transport of implements, &c., is only of secondary or negligible importance.

tainer will now allow of its being pushed right home, and when completely full the cuts *B–B* are worked across to the point *C*. This is necessary to allow for the fall of loose material and the removal of such

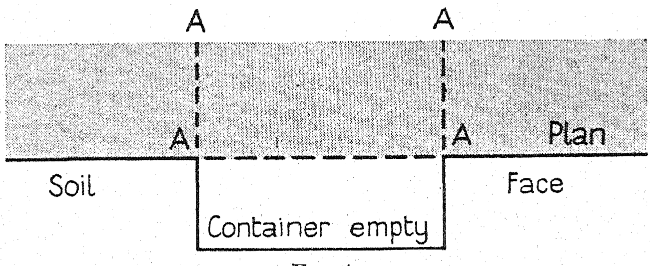


FIG. 4

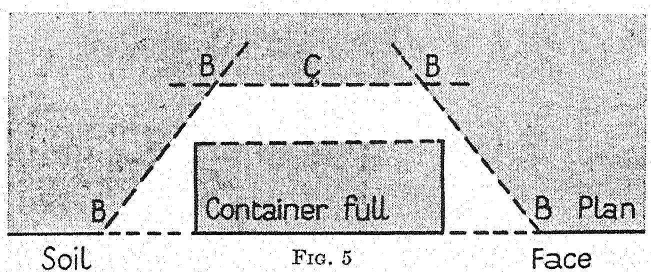


FIG. 5

obstructions as stones or roots. In the case of soils which are likely to crumble or fracture the method of H. Greene (Sudan) has been proved to be of immense value for the preservation of the sample. A 4-inch bandage is wrapped round and round the container as the cutting back proceeds, so that the whole monolith is locked up in one solid piece. When these cuts have been made, the container is pushed half an

inch downwards and a steel slice (or the base clip) is pushed under the base of the full container. If, however, the container is bandaged, this is impossible and must be done when the end-pieces are fitted. The man standing on the top of the pit then pushes the whole block of soil into the arms of the man waiting in the pit. The block of soil in the container now resembles

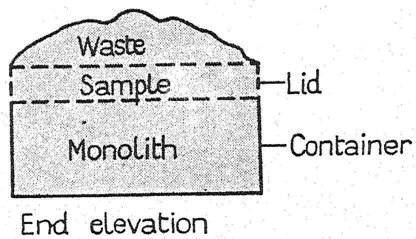


FIG. 6

Fig. 6. If the envelope is used the face of the monolith is cleaned off flush to the edge. The lid is pushed home *over* the container but *inside* the envelope. The envelope is then removed and the end-pieces *fitted* and tacked into place, any loose spaces being carefully plugged with cotton-wool. When no envelope is used the lid and end-pieces may be fitted as convenient.

For soils such as stoneless clays and loams, which will cut clean, a simpler method may be used as shown in Fig. 7.

The initial cuts, *A–A* and *B–B*, are similar, but instead of cutting back to an apex at *C* a cheese wire is pushed under the base clip with a small steep prong or a screw-driver with a notch cut in the blade, and an operator standing astride the monolith draws upward

with a sawing motion as in X–X. With two men drawing it is better if the wires are crossed as in Y–Y, and is in general the easier way.

For samples containing many roots or soft stones

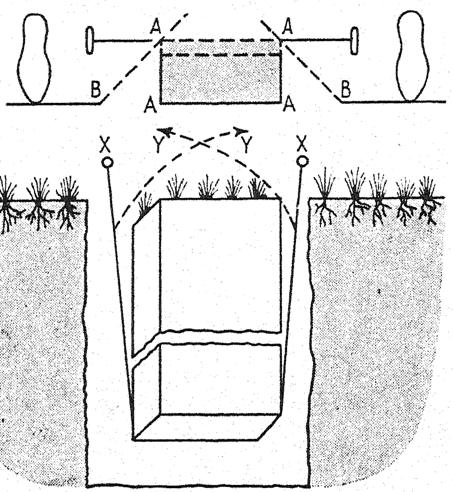


FIG. 7

a section of a band saw set in two handles, bent round the whole container and used by the man in the pit with a sawing motion from side to side, has proved very useful.

Packing and Transport of Monoliths.

In experiments carried out in the Alps of Switzerland in December 1932 it was found possible for one man to transport all the tools and another to transport two or three empty containers through a difference of

altitude of 4,000 feet. On the return journey one man could carry one full container while the other carried tools and an empty container. On rejoining the base

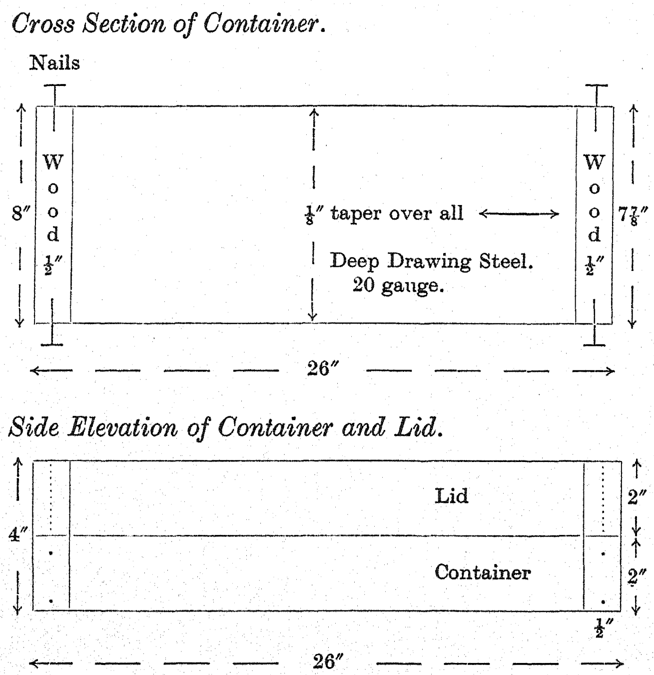


FIG. 8

the containers were packed into a box capable of holding four units. The packing of four containers together is advised, since for rail or sea transport the resulting heavy load precludes careless handling by porters. With adequate external packing, and parti-

cularly where the monolith is plugged with cotton-wool, single sections have been safely received from all parts of the world.

Sampling by Carton.

The use of bags for the collection of samples, though in fairly general use, is not to be recommended; samples dry out and grind down, thus destroying all structural and constitutional features. Bags also have to be of the very finest material to prevent some loss of the finer fractions. In fact, on receiving soils from long distances, it is very rare indeed to find the sample completely intact. Much of this trouble can be got over, however, by the use of ordinary paraffin-waxed cartons, the waxed tops of which, if run round with a lighted match, will melt sufficiently to seal the lids hermetically and so preserve the moisture. Good sampling involves very careful differentiation of horizons, particularly when they are merging. A horizontal cut with the sampling tool (a large butcher's knife) should first be made between the horizons to emphasize the sampling limits, and then two long and deep vertical cuts should be made in the face. If the zone shows little or no structure, a block of the soil may be cut out and neatly placed into the carton bottom side upward and securely packed. If good structural features are apparent, individual elements should be picked out and used as the representative sample of the zone. Friable soils or soils with loose constitution are usually taken easier by lifting out the whole horizon with a spade and then dropping the whole

mass cleanly into the carton so as to preserve as much of the zoning as possible. This procedure seems perhaps a little fussy to the spade-and-auger man, but when the samples are laid out on the bench in the laboratory the additional information obtained for this little extra amount of care is often of very great value. It is a somewhat moot point as to whether consecutive samples should be taken exactly contingent to each other or whether it is better to leave a small margin as waste. As a general rule the author has found that a better horizonal differentiation may be obtained by rejecting as 'waste' all that material disturbed by the cuts between horizons. Particularly is this useful when sampling merging horizons, although it is a point upon which it is hardly wise to dogmatize.

Sampling of the Utilization Layer.

This sample should be, of course, a composite one and representative of the immediate requirements of the land user. It should be taken from a sufficient number of points to eliminate local irregularities, though what this number should be is impossible to foretell. The work of Waynich and Sharpe[1] goes to show that on the whole the number can hardly be too great (6 per acre is a minimum). The depth to which the sample should be taken depends a great deal upon the crop involved; in the case of grassland the sod-layer should always be taken separately, and then a further sample should be taken to the limit of the next visible change, but should not normally exceed

[1] *Agric. Science*, iv, 1919, pp. 121–39.

about 15 inches. On arable land the layer actually turned by cultivation should be taken, with a further sample to the first visible change if desirable. In those soils in which visible characteristics are not apparent some depth must be determined by trial and error based upon the observations of local usage. The best method by which to take the sample is to open a small hole about a spit or so deep with a spade and then take a thin but uniform slice from top to bottom, cutting it off at the required depth while laid out on the spade. Several such slices are taken, thoroughly mixed, and fairly sampled before leaving the field Final mixing and sampling will of course be done during the preparation of the 'fine earth' in the laboratory.

Sampling Instruments.

Though many elaborate tools are available for the sampling of soils, the only tool upon which the field-man absolutely can rely is the spade. The screw auger is of great value in correlation work when mapping the boundaries of profiles already described, but a profile description based on auger sampling alone would be to discount all structural and constitutional features. No boring tool yet devised will entirely eliminate compaction in some form or other, though certain implements of the gouge type, or cheese-sampler type, get very near to perfection. In this connexion the author has used two types with some degree of success.

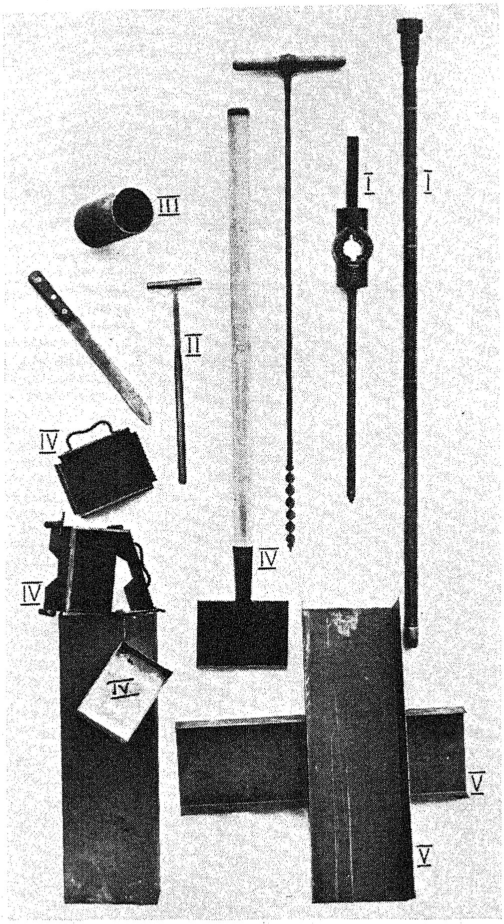
The plate facing p. 138 illustrates some of the types of implements which are used for soil work.

The Peerless Auger (*Parker Machine Works, California*), I.

The Peerless Auger, though a useful tool, requires a little modification and a good deal of experience in application before it will do all that is claimed for it. By its use, however, depth samples may be taken in certain soils, which, if transferred to cardboard map-cylinders of the right bore, may be conveyed to the laboratory, where a composite profile sample can be built up and examined by splitting the cylinder longitudinally with a sharp knife. There are three main field difficulties encountered in using this instrument, however. First, the compaction, for which, of course, there is no remedy. Secondly, the problem of removing the core in one piece. This difficulty may be overcome in some degree by the insertion of an inner ratchet-strip of steel, like the cradle of a Pressler corer, which when withdrawn horizontally and through the cardboard cylinder will bring out the section without fracture. The modification, however, is not yet upon the market. The third, but by no means the least important to the field-man, is the weight. The 14-pound hammer, 6-pound tube, and a bundle of cylinders is an unpleasant burden when working alone. It is, however, the best instrument of its kind with which the author has had any experience.

Gouge Augers, II.

There are many of these on the market and there is but little to choose between them; they all work in



I. Peerless Soil Tube (r.). Driver (l.).
II. Gouge Sampler (Brynmor Thomas).
III. Sod Sampler (Velten).
IV. Monolith Section Sampler (China).
Back plate (top). Hinged cutting box (beneath). Metal sample box (bottom). Guillotine (centre).
V. Monolith container (Clarke). Lid and container. Screw auger and twelve-inch knife unmarked.

certain soils, but none of them works in all soils. For a quick thrust down, a twist, and a pull-up in boundary mapping, they are quicker and easier to use than the screw auger, though the times they come up empty may sometimes be exasperating. The auger in the illustration was designed by Brymor Thomas, and its efficiency is dependent upon the fact that the cross-section is a D and not a C.

The Velten Soil Sampler, III.

This instrument was designed by E. C. W. Velten for the taking of grassland and peat samples. It is a wide and short steel cylinder with a cutting-edge at the base so designed as to have a slightly larger inside diameter than the diameter of the cutting-edge; this allows the sod to slide out on inversion without bind or fracture. It is made so that the internal content is exactly 1 litre to enable determination of volume-weight, porosity, &c., to be readily obtained. Since the ratio of height to cross-section is only about 2:1, the amount of compaction is practically negligible, and in certain soils it is possible to take a succession of samples down a profile by pressing the instrument into the soil, digging round it, cutting it off sharp and clean and going on again. Similar instruments have been used in Switzerland and Russia with excellent results.

The Chinese Geological Survey method for the profile sampling of wet soils, IV.

This is an elaborate but very efficient instrument and is meant to be used for the sampling of an already

prepared profile pit. The rectangular box of hard steel has four cutting-edges, all hinged together at the corners and screwed to a heavy steel removable back-plate. Inside the assembled box is a thin metal, accurately fitting, lidless box. The whole apparatus is driven square into the face of the profile pit until the box is full; a large spade-like cutting tool is then forced down behind the sample to sever it from the main soil mass. The apparatus is lifted out, unscrewed, and the thin metal box removed with its sample intact; a push-on lid is then fitted and the sample is ready for erection as a unit in a composite monolith or it may be used as a sample for analysis. The apparatus, though useful, is not quite so good as the Oxford container V because it does not completely eliminate compaction, while the weight of the outfit is also very much greater.

IV

SOIL SURVEY AND MAPPING

THE placing on record, by means of a soil map, of the information gathered in the field is a natural corollary of all that has been discussed in the previous section. Experience in soil cartography must, however, be acquired in the field, since a good soil map may only be prepared after exhaustive perambulations, borings, and diggings. Assuming that the student has acquired a certain amount of knowledge in field sketching and map making in his earlier studies, the general procedure is fairly simple. If, however, the student requires some general knowledge on the subject, he cannot do better than read the War Office *Manual of Field Sketching*,[1] which is quite comprehensive enough for all ordinary purposes, including the use and reading of air photographs.

Use of Maps.

For the purpose of this book it must be assumed that the surveyor has access to adequate base maps which are accurately made and properly contoured. The maps of H.M. Ordnance Survey and H.M. Geological Survey supply practically all the detail that is needed. The maps which are in most general use and are published in Britain, India, Canada, and U.S.A. are usually scaled to show the relation between *inches* on the map and *miles* on the ground. Those generally selected in England for soil-mapping purposes are the one-quarter

[1] See footnote on p. 144.

inch to one mile (R.F. 1 : 253,440) and the one-inch to one mile (R.F. 1 : 63,360) Popular Edition maps which are mainly used for reconnaissance and regional survey, and the six inches to one mile map (R.F. 1 : 10,560) which is used for intensive and utilization survey. The 'twenty-five inches to the mile' scale is rarely used except for the plotting of drainage systems or other particularly detailed operations.

Foreign maps and maps of most British Colonies are usually scaled on the decimal system so as to give an R.F. of 1 : 10,000 (Egypt); 1 : 100,000 (Europe), or 1 : 250,000 (Colonies, &c.). The International map is made with the R.F. 1 : 1,000,000, which on an English basis works out to one-sixteenth of an inch to an English mile or sixteen miles to one inch.

The map used by the English Soil Survey for Series mapping is usually referred to as the 'Six-inch Ordnance Survey' and is issued in full and quarter sheets. The unit of a map used in the field is known as a 'field slip' and is prepared by dividing a quarter sheet into two halves by cutting it north and south to give an east and a west 'field slip'. The use of this form of field slip for soil survey purposes has been adopted from the practice of H.M. Geological Survey and, in fact, most field practice is worked out on the lines used by the Geological Survey when 'Drift Mapping', but modified to suit Soil Series requirements.

Scales.

When using maps in the field it is often convenient to have some idea of the correlation between inches on the map and yards on the ground, without the

actual use of scales. Maps warp and stretch on service and so absolute accuracy is hardly to be expected, but the following list of scales has been drawn up to help the beginner better to visualize his 'lie of the land'.

Map scale	*R/F*	*1 in. on map*	=	*yds. on ground*	*100 yds. on ground*	=	*in. on map*
25 in. to 1 mile	1/2,534	1 in.		70	100		1·4 in.
6 ,, ,, ,,	1/10,560	,,		293	,,		0·34 ,, (1/3)
4 ,, ,, ,,	1/15,840	,,		440	,,		0·23 ,, (1/4)
1 ,, ,, ,,	1/63,360	,,		1,760	,,		0·057 ,, (1/16)
1/2 ,, ,, ,,		0·1 in.		350			
1/4 ,, ,, ,,		,, ,,		700			
1/10 ,, ,, ,,		,, ,,		1,760			

Indoor Preparation.

Before the surveyor goes out to the field at all he should spend some time in becoming quite familiar with the general conditions prevailing in his area. He should endeavour to construct a mental picture of the main and mezzo topography, the solid and drift geology, and the distribution of land utilization (woodland, parkland, wastes, arable, &c.). In addition to the above he should then study the natural drainage (which is usually fairly obvious) with special reference to any artificial improvements, such as the locking of rivers and the distribution of canals, leats, rines, dykes, &c. These items are very important because the whole pedological processes of a region may be changed by such means in a comparatively short period of time. For example, the artificial lowering of the gley zone by a fall of a few inches in the height of the permanent water-table may be responsible for the reclamation of

a naturally swampy forest soil or a meadow to one of considerable agricultural value.

He should next study the accessibility of the area and work out a scheme of traversing which will allow him to cover the greatest possible area of ground with the minimum amount of recrossing of already mapped areas. For this purpose it is often useful to select a road, railway, or natural feature from which offsets may be made and spots marked on the map for purposes of location finding. In unmapped country, or where adequate base maps are not available, much very valuable information may be obtained from a study of aerial photographs. Overlap photographs when examined under a topographical stereoscope give a beautiful picture of the 'lie of the land', the drainage and general utilization. The full interpretation of air photographs is only possible by the expert, but a novice may become quite proficient in the recognition of localities and the differentiation of regional characteristics after but little practice.[1] The full use of air photographs for the actual soil survey has yet to be made possible for reasons which become obvious during survey, but even in well-mapped country the use of an air photograph for location finding, &c., greatly speeds up the work.

The field slip used by the English Soil Survey is carried in a stiff leather case which is used as a drawing board, but which is not always as convenient as it might be, especially when making use of air photo-

[1] The reader is recommended to read the *Manual of Map Reading, Photograph Reading, and Field Sketching.* War Office, 1929. 3*s*.

graphs (these are not, however, officially used by the English Soil Survey Conference).

For his own mapping and for teaching purposes the writer makes use of a small drawing-board of five-ply wood as a plane table, with the map or air photograph, which may be interchangeable, pinned beneath a pinned sheet of xylonite. Xylonite is the material from which photographic films are made, and may be obtained with a matt surface on one side and plain glazed on the other. It is cheap, and possesses advantages over the ordinary field slip in that it is waterproof and so will allow of mapping in the rain; it will retain pencil marks as well and as long as paper, and the surveyor may draw his map with muddy fingers without injury to the fair map beneath. On return to base the detail may be inked in with a waterproof or special cellulose ink and then the film can be washed free of all undesirable matter. When using the xylonite cover, the writer usually traces off the drift geology and the traverse lines before leaving the base, so that field work with a separate geological map is not needed. The transferring of the fair xylonite copy to the base map is done quite easily by using a plate glass drawing board with a lamp beneath.

Field Mapping.

This part of the work, if the indoor work has been efficient, and the area to be surveyed is well mapped and known, though requiring a certain amount of hard manual labour is merely a matter of finding and delimiting the boundaries by sampling with an auger around the typical sites worked out beforehand and

exemplified in the profile pits. The correct siting of profile pits, however, is of course the whole basis of an efficient survey and cannot always be done beforehand, even by the use of the best-made maps. In countries where the surveyor has to conduct a survey over ground to be opened up to some new system of utilization (e.g. tropical bush into arable land) he may find himself compelled to add to his map much more matter of a purely topographical character. In such cases quite important details with reference to aspect, altitude, slope, and outcrops are difficult to assess without an actual determination upon the site itself. For these purposes and for the determination of the data to construct a topographic profile the knowledge of the use of a few simple instruments is needed. The following hints on the use of instruments and the interpretation of data may be of some general use to the beginner.

Measurement of Slopes and Gradients.

There are three different methods at present in common use for expressing gradient or slope and the method selected depends chiefly upon the type of instrument used. Abney levels and many clinometers indicate the angle of the slope with the horizon, in degrees and minutes. Other instruments, such as the De Lisle clinometer, indicate the tangent or the ratio of height to horizontal distance, e.g. 1 in 15. In America a gradient or slope is usually expressed as a percentage, or the number of units of rise or fall per 100 units of horizontal distance, and American instruments are graduated accordingly.

The table shows the ratios and percentages corresponding to different angles of inclination or slope. In the absence of a table, angles can be converted to equivalent ratios by dividing the angle, measured in minutes, into 3438; e.g. Angle 3° 49′ = 229′, and $\frac{3438}{229} = 15$, and the slope is 1 in 15. This method is sufficiently accurate for practical purposes.

It should be noted that very steep slopes, such as the sides of embankments or excavations, are often expressed as the relation of horizontal length *to* height, i.e. 3 *to* 1 indicates a basal length of 3 units *to* 1 unit of height, which is the converse of the usual method of expressing gradient.

Measurements of Slopes: Table of Equivalents and Corrections

Angle of inclination	*Equivalent Tangential ratio*	*Percentage, or rise in ft. per 100 ft. of distance.**	*Correction in length for 100-ft. chain*		*Correction in length for 66-ft. chain*	
		ft.	*ft.*	*in.*	*ft.*	*in.*
0° 10′	1 in 343	0·29	0	0	0	0
0° 20′	172	0·58	0	0	0	0
0° 30′	114	0·87	0	0	0	0
1° 0′	57	1·74	0	0	0	0
2° 0′	28	3·49	0	1	0	0
3° 0′	19	5·24	0	2	0	1
4° 0′	14	6·99	0	3	0	2
5° 0′	11	8·75	0	5	0	3
6° 0′	10	10·51	0	7	0	4
7° 0′	8	12·28	0	9	0	6
8° 0′	7	14·05	1	0	0	8
9° 0′	6	15·84	1	3	0	10
10° 0′	6	17·63	1	7	1	0
11° 0′	5	19·44	1	10	1	3
12° 0′	5	21·26	2	3	1	6
13° 0′	4	23·09	2	8	1	9
14° 0′	4	24·93	3	1	2	0
15° 0′	4	26·80	3	6	2	4
16° 0′	3	28·67	4	0	2	8
17° 0′	3	30·57	4	7	3	0
18° 0′	3	32·49	5	2	3	5
19° 0′	3	34·43	5	9	3	10
20° 0′	3	36·40	6	5	4	3

* When using the 66-ft. (i.e. 100-link) chain these same numbers are used in terms of links.

The Use of an Abney Level in Topographical Surveying

An Abney level, used in conjunction with a chain or steel tape, is of great help when filling in topographical detail on an existing map, and it gives results which are sufficiently accurate for soil survey work.

Steel tapes are often better than chains for field work as, with normal use, any appreciable stretching or alteration in length need not be expected. A tape does not collect grass or rubbish when dragged along the ground, but it is less flexible than a chain and is more liable to break, hence needs greater care in handling. The 100-foot tape, divided into feet, is the most useful length for general purposes and the best suited for use with an Abney level, but the Gunter chain or tape, of 66 feet, is often used where the measurement of acreage is required and has, therefore, been included in the table.

Abney levels of many types and qualities are now obtainable, and for topographical work it is of considerable advantage to use a level with a subsidiary scale showing percentages or 'units of rise per 100 units of length', in addition to the usual angle graduations.[1]

Special 'topographic' Abney levels are used in America and Canada, with additional 'trailer' tapes to obviate the use of slope correction tables and to simplify chaining, but these instruments are difficult to obtain outside the country of origin and are unnecessary.

[1] This type of Abney level is now obtainable in England for about £3 10*s*.

As Abney levels depend upon the relation between a sight tube and a small spirit-level they easily get out of adjustment and should always be checked immediately before use. Necessary adjustments can quickly be made by the use of the small screws at the ends of the spirit-level.

A staff should always be used to support an Abney level, and all readings should be taken on to a second staff or a boning rod of the same height, marked off in feet and half-feet for use in levelling, and fitted with a crosspiece or sight-vane.

It should be remembered that in survey work all distances are measured with reference to the horizontal plane so that the plan of the survey may be a true projection of the ground. Hence, in chaining on a slope of more than 3°, unless the chain or tape can be held horizontally by 'stepping' in ½- or ¼-chain lengths, a correction to obtain the horizontal equivalent for the slope must be made. The table gives the necessary corrections for angles of inclination from 10′ to 20°, and for both 100-foot and Gunter chains. These correction lengths are deducted from the slope chainage totals. It will be seen from the table that for angles of less than 3° the amount of correction is negligible.

When using an Abney level for finding differences in elevation if the distance is short, the instrument may be set at zero and used as a simple level. For longer ranges or steep slopes, the inclination per cent. should be read, and the distance measured with the 100-foot tape. A reading of 6 per cent. then indicates a rise or fall of 6 feet for each 100-foot chain length

and 0·06 for each additional foot. Hence, for a corrected horizontal distance of 312 feet and an observed slope of 6 per cent., the difference in elevation or height is $3{\cdot}12 \times 6 = 18{\cdot}72$ feet.

It is important to ensure that a new reading is taken at each change in the slope or gradient.

When plotting the results of an Abney level survey into the field book the use of squared paper, with the squares subdivided into tenths, will be found to be of considerable help. Full instruction for the construction of a detailed traverse are given in article 142 on p. 116 of the War Office Manual previously described.

There are two general methods of attack which may be adopted, depending mainly upon whether the area is 'open', as in a grass or arable region, or 'difficult', as in woodland or in regions of broken topography.

Open Country Survey.

The surveyor walks on to one of his spot points, which, if possible, should be the highest point with the broadest view in the region. Then, having taken the site characteristics into consideration, he bores about with the auger until he is satisfied that he has found a representative profile spot for his profile description. Here he prepares his pit and marks his map with a triangle and number (△). Having described the profile, he traverses towards his next spot point, taking borings either at regular intervals or in relation to every change of vegetation or edaphic feature, until he notes a change of sufficient significance to warrant further investigation. At this point the field-man only may

decide, and this is only possible after experience on the spot and cannot possibly be described here. It may help, however, if certain points are dealt with.

Changes in soil profile may be expected to occur in each or all of the following circumstances:

a. A change in the nature of the lithological material.

b. A change in the topography.

c. A change in the vegetation, which if on arable land may be looked for in the nature and quality of hedgerows, timber, &c.

d. Changes in colour.

e. A difference in the sound produced, and feel to the feet when walking or stamping. This test to the experienced field-man is frequently of very great value.

If the surveyor travels from, say, permanent grassland with a good sod formation to old arable land low in humus, he must be prepared to discount the A horizon to some extent and work on the *depth* of horizons and the characteristics of the B, G, and C horizons. He must bear in mind that he is mapping soils and is not mapping systems of utilization or the idiosyncrasies of neighbouring farmers. For the bringing into agricultural use of the land of virgin prairie or steppe the Soil Series map is of great value, but in areas which have developed into a sort of large-scale pot culture the Series map may frequently prove of little assistance to agricultural practice, because man's utilization frequently differs from one area to another on an otherwise uniform site.

Survey in 'Difficult' Country.

By difficult country is meant areas under forest, very broken topography, &c. In this case the art of locality finding must be learnt by experience, but the beginner may make a very good soil map with the aid of compass bearings, chaining or pacing, and inspection pits at arbitrary intervals. By bracketing between inspection pits, soil boundaries may be sketched in with a good deal of accuracy, but depending greatly, of course, upon the spaces left unchecked. In ordinary woodland survey in England the writer has found that if, in conjunction with the main and mezzo topography, 'lines' are run at about two- or three-chain intervals (at right angles to the feature whenever possible), with inspection pits at regular chain intervals and additional pits at every change in mezzo-relief, a very small area of land remains unclassified after a little bracketing. The great temptation for the beginner to use rides, fire avenues and odd small clearings as sites because they 'look nice' must be discouraged, though they may, and should, be used as location points wherever possible. In the preparation of the inspection pits it is not usual to dig more than the absolute minimum necessary to give the surveyor the information he requires; the standard profile pit is used only once for the full recording and sampling of each true soil site and series.

V

MAIN POINTS IN SOME SYSTEMS OF SOIL MAPPING AND CLASSIFICATION

AGRONOMIC AND AGROGEOLOGICAL METHODS

THESE methods are usually concerned with attempts to map 'land values' or assess 'fertility' by plotting on a base map the data obtained by the chemical and physical analysis of representative soil samples, in a series of isolines. The various methods employed in obtaining the necessary data differ slightly in different countries, but it appears that for the rationalization of utilization, evaluation of land, and the mapping of soils in the intensively cultivated areas of central and western Europe, the principle is, in general, a sound one.

In Russia use has been made of iso-humus lines and iso-carbonate lines in the mapping of some of the productive regions of the Ukraine, but this is now discontinued in favour of the 'landscape' method (see p. 163).

In England the nearest approach to such methods has been produced by advisory officers, &c., in the preparation of acidity maps or lime deficiency maps during their routine investigations in their provinces.

Certain countries in which German influence in soil science is most generally accepted make use of what is termed the Bodenbonitierung or Bonität Scala.

The Bodenbonitierung or Bonität Scala

Numerous systems have been evolved for the evaluation of land, and a good deal of detailed discussion on

the subject may be found in Blanck's *Handbuch der Bodenlehre*. The general principle underlying most of the schemes, however, is the evaluation of the land unit on the basis of the summation of the points awarded after an examination of certain factors contributory to the economic agricultural production of the soil regions. It will suffice here, however, if we take for an example the scheme evolved by Fackler for use in Bavaria.

Fackler assesses the soil region on three main contributory factors:

The soil conditions.

The climatic-vegetation complex.

The economics of transport.

The region is examined and points are awarded on field observation according to the following categories:

The Soil conditions.

(1) General Texture, Structure, Constitution, and Humus.

Best Humus Loam	30
Sandy Loam	20
Sands	9
Chalk	5

(2) Quality of the ploughed layer (structure and humus).

Very good Upper Crumb	10
good Upper Crumb	5

(3) Quality of subsoil in relation to the Upper Crumb (structure, constitution, depth, &c.)

Very good	15
good	10
tolerable	6
bad	3

(4) Soil moisture conditions.

Very good (perfection of drainage, adequate moisture retention, &c.)	10
good	8
satisfactory	6
generally satisfactory but liable to be wet or dry	4
tolerably satisfactory but liable to be too wet or too dry	2
continually wet or continually dry	0

(5) Topography.

Level	10
Undulating	5
Hilly or broken	0

(6) Cultivation, manuring, and reserves of plant nutrients.

Very good	15
good	10
tolerable	5

Possible marks for soil conditions 90.

Climatic-vegetation complex.

Situation of region with reference to optimum conditions.

Wine region	10
Wheat region	6
Rye region	4
Mountain region	0

Danger of hail in region.

Little risk	10
Moderate risk	5
Frequent risk	0

Possible marks 20.

Economics of transport.

Distance from railhead.

Less than 5 kilometres	10
Between 5 and 10 kilometres	5
Over 10 kilometres	0

Total possible marks for the Perfect Region 120.

Fackler then proceeds to divide the marks awarded into twelve groups to correspond with the valuation of the land in terms of money marks of the Department of Finance.

Group	I.	120–111	900–800 Marks
	II.	110–101	800–700 ,,
	III.	100–91	700–600 ,,
	IV.	90–81	600–500 ,,
	V.	80–71	500–400 ,,
	VI.	70–61	400–350 ,,
	VII.	60–51	350–300 ,,
	VIII.	50–41	300–250 ,,
	IX.	40–31	250–200 ,,
	X.	30–21	200–150 ,,
	XI.	20–11	150–100 ,,
	XII.	10–5	100–50 ,,

The Hungarian System of Kreybig De Madar

This system of soil cartography has been employed by the Royal Hungarian Geological Survey in the preparation of their soil maps on the scale of 1 : 25,000. Some of these maps were exhibited at the Third International Congress of Soil Science, Oxford, in 1935, and it is from Dr. Kreybig's notes that this abstract was obtained.

The general principles have much in common with other rationalization schemes whereby 'land value' and crop production are correlated with pedological data obtained by site and profile examinations. It is discussed here at some length because it is one of the latest pieces of work published on this subject. The 'productive value' of the soil depends upon its fertility, which is estimated from the determination of

the maximum yields of various plants and the cost of their production. This productivity is the result of the interaction of certain factors which are studied both in the field and in the laboratory, and may be summarized as:

I. Climate.
II. Topography with special reference to *micro-relief*.
III. The geological origin of the soil mass.
IV. Human influence, methods of land utilization and treatment by cultivation, manure, &c.
V. The Soil Profile. The study of which includes the determination of the physical and chemical properties.
   a. The content and nature of the humus.
   b. The depth of the soil used by the plants.
   c. The depth of the subsoil.
   d. The depth, movements, and nature of the ground-water.

Field Methods.

On the points of intersection of a network of lines based upon topographical data inspection pits are prepared. These sites are numbered and shown on the base map. The site and profile characteristics are then recorded on the 'field work questionnaire' in the following order:

I. Date and weather.
II. Serial number and depth at which analytical sample is taken.

III. Topography.

IV. Stratification [each layer described in order].

Depth of layer in centimetres.
Moisture conditions.
Colour.
Kind of soil.
Structure.
Depth of humus layer in centimetres.
Depth of wheat or corn roots in centimetres.
pH value.
Calcium Carbonate.
Last crop taken.
Special notes: depth of water-table.

The method of assessing the various characteristics and their expression by conventional signs is specific for the country, but it portrays a strong Russian influence.

Topographical Position. Four categories are used:

Depression site.
Slope ,,
Elevated ,,
Flat ,,

Moisture Condition. This is determined by the senses of touch and sight.

0	air dry.
+	weakly moist.
++	moist but will change colour on further wetting.
+++	no change of colour on further wetting.
++++	waterlogged.

Kinds of Soil.

Under this heading is included the texture, the mode of formation, and to some extent the geological nature of the soil mass. The 'kinds' are diagnosed by touch, and from observations of the reaction to acid and indicators.

	Clay
Meadow	Clay
Loamy	Clay
	Loam
Clayey	Sand
Loamy	Sand
Fine	Sand
Coarse	Sand
	Grit
	Gravel
	Stony
	Alluvial
	Mud
	Gleyey
	Alkaline
	Loess
Sodium	Loess
Magnesium	Loess
Lacustrine	Clay
	Peats

Structure.

This item appears to include not only the soil structure as generally understood, but also the general constitution, consistence, and chemical deposits of the horizon.

Crumb (Excellent)
Crumb (Good)
Prismatic
Polygonal

	Laminated
	Sandy (probably single-grained)
	Dust
	Structureless
	Dense or Tenacious
	Pitchlike or Tacky
	Cracks or clefts
With	Calcareous concretions
,,	,, veins
,,	,, spots
,,	Gypsum efflorescences
,,	Ferruginous veins
,,	,, concretions
,,	Vivianite
,,	Efflorescences of Salts

Depth of Humus.

This describes the depth to which the intimate humus is distributed in the whole soil mass, and does not include the Hesselman Layers.

Calcium Carbonate.

The presence or absence of carbonate is determined by the violence of the reaction to acid. Four categories are employed:

0	nil			
+	little	$<$	5	per cent. approx.
++	much	$>$	5	,, ,, ,,
+++	violent	$>$	10	,, ,, ,,

Laboratory Data.

Laboratory investigations are extremely comprehensive, but although each horizon is examined with

meticulous care both for physical and chemical properties, no data are given for the analysis of the clay fraction. The following series of determinations are made, and set out as in the table which is published as a memoir accompanying the map.

GENERAL DATA (1)

Serial no. and depth of sample	Physical Character (*Kind*)	Soil Type	Mapping Colour and Symbols

CHEMICAL DATA (2)

pH by H_2O	pH by KCl	Hydrol. acidity	$CaCO_3$	Water sol. salts	Na_2CO_3	$\overset{+}{H}CO_3$	$\overset{=}{SO_4}$	$\overset{-}{Cl}$

Exchangeable bases $\overset{++}{Ca}$	$\overset{++}{Mg}$	$\overset{+}{K}$	$\overset{+}{Na}$	(S)	T–S	V	Nutrient stat. C%	N%	C/N	P_2O_5%	K_2O%	Humus

PHYSICAL DATA (3)

Moisture	Mechanical Composition Dispersion by Li_2CO_3: Sand mm. 2–0·2	0·2–0·02	0·02–0·002	Clay <0·002	Structure Factor	Capillary water lift in mm. per hours: 20 hrs.	100 hrs.

Critical layer Thickness	% Linear shrinkage	% Relation between Soil	Water	Air	Min. pore space	Min. water cap.

The Production of the Map.

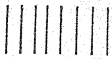
Three conventional characteristics are employed to express detail in the final map:

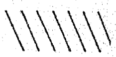
(*a*) colouring;
(*b*) hachuring;
(*c*) numbering [enumeration points of plant nutrients and ground-water level].

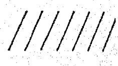
Colouring. Colours are used to show the soil type and class with certain chemical characteristics such as lime deficiency or alkalinity; for example:

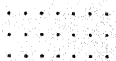
Blue. Steppe soils with no lime requirement.
Red. Acid meadow-clay and degraded steppe soils —lime required.
Mauve. First class alkali.
Lt. Mauve. Second class alkali
—and so on.

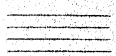
Hachuring. Superposed on the colours are hachures to denote physical characteristics; for example:

Deep soil with excellent structure and water conditions. 

Deep soils with good structure and water conditions. 

Deep, very binding, badly permeable soils. 

Deep sandy soils, very permeable. Low water capacity. 

Shallow steppe and meadow-clay soils. 

Enumeration. In each site as defined by the foregoing conventions a small circle is placed in which is a series of figures expressed like a fraction. $\frac{513}{80,3}$

The Numerator. The first figure indicates the quantity of humus near the surface by the following scale:

1	1	per cent.
2	1–2	,,
3	2–3	,,
4	3–4	,,
5	4–5	,,
6	5–8	,,
7	8–15	,,

The second figure indicates the total *phosphoric* acid, by the following scale:

1	0·05–0·1	per cent.
2	0·1 –0·15	,,
3	0·15–0·2	,,
4	0·2 –0·3	,,
5	over 0·3	,,

The third figure indicates the total *potash* on the same scale.

The Denominator. The first number indicates the depth of the humus layer in centimetres.

The second figure [separated by a comma] indicates the depth of the ground-water level in metres.

In the opinion of the writer this method of cartography has much to recommend it, but it must be remembered that the labour and costs entailed for its production are tremendous. It is, however, of great use to surveyors in that it is constructive, and from it many useful hints may be obtained for use in other surveys.

The Russian System of Landscape Survey

Since *The Study of the Soil in the Field* has been produced mainly as the result of the writer's impressions of the Russian system of soil study, little further description is needed beyond an outline of the

general field methods employed in that country. There appears to be but little difference between Landscape Survey in Russia and Regional Survey as it is usually understood in this country. Use is made of the Soil Region and the connexion between the soils and the geomorphology of a region is invariably emphasized, and particular attention is paid to micro-relief and vegetation.

The field preparation of a map extends over a period of at least two years. In the first year the whole area is traversed on horse-back and a rough soil map is prepared from the relief and vegetation, confirmed by a few chemical and physical analyses of characteristic soil samples. The scale of this map usually corresponds to the half-inch to one mile or quarter-inch to one mile maps of the English Ordnance Survey. In the second year the area is divided into smaller units, and the staff of surveyors increased to allow of more intensive work. The same general lines of approach are used, but the scale of mapping is increased to approximately two inches to one mile, which allows of the delimitation of the 'Soil Individual' or 'Soil Variety'.

The 'Soil Individual' occurs in that small area traversed by a uniform soil section. Soil investigations approach this limit when Soil Varieties modify very rapidly in conditions of very slight undulation of micro-relief, as, for example, in the saline regions when such soils are recognized as 'Soil Complexes' The limit of the extent of these soils is obtained by the digging of control ditches, and then from their subsequent study and description by the morphological method the soil map is ultimately constructed.

Prasolov[1] sums up *Landscape Survey* in the following words:

'Landscape units themselves also form genetically connected systems, based on the principles of geographical cycles. The interdependence of the elements of these units, relief, soils, and vegetation, is frequently so definite, that the knowledge of one is sufficient to reconstruct the two others. Detailed investigations lead to the assumption of an interrelation of geo-botanical units, or of *plant associations* with the units of soil classification, i.e. natural *soil varieties*. The geographical boundaries of the latter will consequently be the last link of the chain of sub-division, to which the soil cartography is leading us by means of successive inferences. Thus the following range of units of soil geography is obtained:

'*Zone — province — region — elementary landscape — soil complex — soil variety*.'

The Macaulay Institute for Soil Research (Method of A. Muir)

The following description of the method has been obtained from notes supplied by A. Muir. It is a modification of the general Russian System to suit his requirements. The field work is carried out on very similar lines to those described in the main portion of this book, though the form of the questionnaire is somewhat different.

The profile form is a double sheet of paper about 7 inches × 11 inches punched on the short side for inclusion in a loose-leaf cover. The front page is devoted to what may be termed the site characteristics (section I) and is spaced as follows:

[1] Prasolov, *Cartography of Soils*, Leningrad, 1927.

THE MACAULAY INSTITUTE FOR SOIL RESEARCH

DATE .... No. OF PIT ....

(1) LOCALITY (CO-ORDINATES OF PIT) ....

....

(2) CHARACTERISTICS OF LOCAL LAND FORMS ....

....

....

(3) PART OF LOCAL LAND FORM ON WHICH PIT IS DUG ....

....

(4) (a) ANGLE ....

(b) ASPECT ....

(c) HEIGHT ....

(5) VEGETATION ....

....

....

(6) PARENT MATERIAL ....

(7) UNDERLYING ROCK ....

(8) DEFINITION OF SOIL ....

(9)

The inside pages are divided into sixteen vertical columns with the title dealing with each of the morphological characteristics at the top, so that the profile description descends in the same order as the soil horizons occur.

Col. 0 Depth in Cm.	1 Colour of profile	2 Humus dist.	3 Ochre Spots and Layers	4 Index of Podsol.	5 Index of Gleying	6 Carbonate	7 Structure

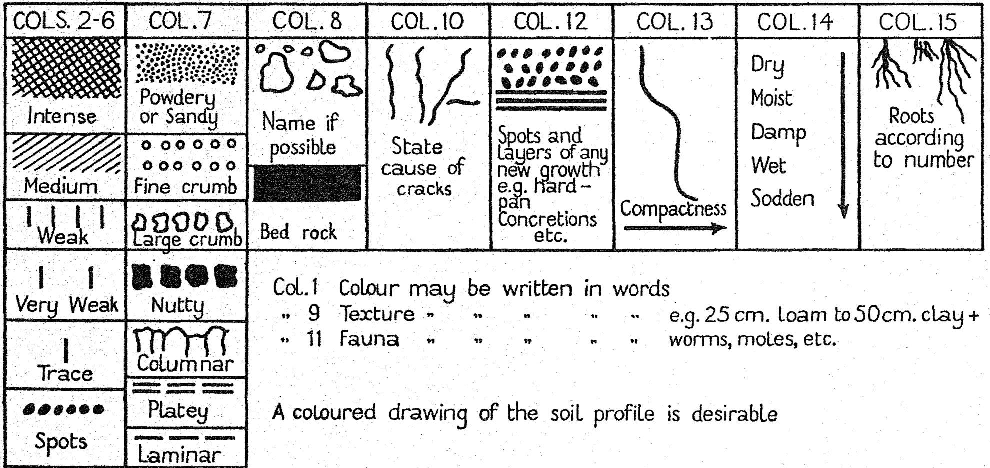
8 Occurrence of Rock or Rock fragments	9 Mech. comp.	10 Fissures and Cavities	11 Soil Fauna	12 New Formation Concretions	13 Compaction	14 Moisture at Time of Observation	15 Root System

On the back page is written a word picture of the soil and any other data for which no column is especially allotted. The following notes on filling in profile forms accompany the covers.

Front page.

1. *Locality.* Spot where pit is dug, or natural section exposed with any reference to nearby place as aid to location. Spot to be marked on map.

2. *Local land forms.* e.g. Valley, watershed, &c., to be named; extent, &c. Nature of valley; terraces; slope of sides, flood plain present, &c. Watershed; rolling, sharp-edged, &c.



Col. 1 Colour may be written in words
" 9 Texture " " " " " e.g. 25 cm. loam to 50 cm. clay +
" 11 Fauna " " " " " worms, moles, etc.

A coloured drawing of the soil profile is desirable

3. *Part of Local land form*. Valley floor, terrace, overflow channel, &c.

4. *a*. Angle of slope.
   b. Aspect.
   c. Height O.D.

5. *Vegetation*. Typical vegetation of the part of the local land form at the pit site.

6. *Parent Material*. Solid geological rock, Drift, Boulder Clay, &c.

7. *Underlying Rock*. Massive mineral material beneath soil-forming material.

8. *Definition of Soil*. World group, type, sub-type, &c.

9. In the grid should be drawn a scaled diagram of the topographic profile and the relative position of soil pits.

The American System of Soil Classification[1]

The soils are defined and classified on the basis of the characteristics of the *soils themselves* rather than on their *relationship* to other bodies such as the *geology*, *climate*, *natural vegetation* or crops. The unit of classification is the *Soil Type* which is a combination of a *Series Name* and a *Class* (texture) name, e.g. Sassafras Loam, in which *Sassafras* indicates the Series name and *Loam* the Class (texture) name, the two names together representing the Soil Type.

The Soil Series.

This is based upon the following soil characteristics:

I. Geological Origin of Parent Material.

II. Mode of formation.

[1] *The American Method of Soil Classification and Survey*. L. L. Lee. Tech. Com. No. 6, Imp. Bur. Soil Science, 1930.

III. Topographical position.
IV. Drainage.
V. Profile.

The Soil Class (*Texture*).

The soil texture is taken of the *surface soil only*. The classification of the particle sizes of the fractions adopted is as follows:

Fine Gravél	2–1 mm.
Coarse Sand	1–0·5
Medium Sand	0·5–0·25
Fine Sand	0·25–0·1
Very Fine Sand	0·1–0·05
Silt	0·05–0·005
Clay	0·005 to infinity.

The group names for texture classes are divided into twenty categories and are set out on p. 83 during the discussion of Texture (Item 6).

There are two kinds of survey in use in the U.S.A., viz. reconnaissance surveys and detailed surveys. The former is usually on a basis of about ten miles to the inch, while the latter is rarely more elaborate than one mile to the inch. (It becomes obvious, therefore, that for highly cultivated areas such as occur in Europe some cognizance must be taken of items ignored by the general field-man in America.) At this point, however, the writer cannot do better than quote some of the remarks of the late Dr. C. F. Marbut when issuing instructions to his field-men.

'The response of the soil survey staff to the circulars of the last year or two regarding the study of the *soil profile* has been very gratifying. A great improvement in our point

of view and our method of approach to the soil and in the description of the soils in the Soil Survey reports has been brought about. While all this is true it is equally true that we have not yet reached perfection along any of these lines.'[1]

He then goes on to explain the work of the pedologist and the needs and reasons for a system of utilitarian classification.

'Returning now to the characteristics on which we must base a soil classification let us see what questions we ask of our soils. Soil characteristics have been referred to in this paper very often and they are doubtless abundant, but what are those of most importance and to which attention must be directed? You will recall that one of the fundamental propositions formulated above stated that all soils at maturity develop a soil profile, and that the features of the soil is expressed in the features of this profile. What are the features of the profile that we seek? In actual practice we have been forced by the weight of facts to determine the following:

1. Number of horizons in the soil profile.
2. Colour of the various horizons, with special emphasis on the surface one or two.
3. Texture of the horizons.
4. Structure of the horizons.
5. Relative arrangement of the horizons.
6. Chemical composition of the horizons.
7. Thickness of the horizons.
8. The thickness of the true soil.
9. The character of the soil material.
10. The geology of the soil material.

'All of you are familiar with the fact that the ultimate soil unit, the soil type, the species, includes all areas of soil having a uniform profile—uniform in all respects. You are also familiar with the fact that the soil series, or soil genus,

[1] *Circular of Instructions*, C. F. Marbut, published in England as Paper No. 22, English Soil Survey Conference.

includes all areas of soil having profiles that are uniform in all respects except that of the texture of the surface horizon, or the upper two horizons in those cases where the surface horizon is very thin.

'The profile of the mature soil at any given locality is characterized by certain fundamental features that are characteristic of such soils over a wide area of country. Throughout such a region all mature soils will have profiles essentially alike in their broad features, and which will be wholly unlike the profiles in certain other regions. By accumulating and analysing the information regarding soil profiles of mature soils over a region like the United States and grouping them according to similarity of general features we are able thus to determine what the common and therefore important features of the soils of the region are, assuming that features of wide extent are important, and by correlating these with other natural features and with natural forces and processes determine their relation to the latter and the causes of their development.

'The mature profiles within any given region will not be identical but they will be comparable, and variations will be confined to unimportant details. The profiles should have the same number of horizons, the colours of corresponding horizons should vary but slightly, the arrangement or relative order of the horizons should be the same in all, the structure of corresponding horizons should be uniform and the depth to the parent material should be approximately uniform in soils of uniform texture. They will vary within narrow limits in the thickness of the several horizons, in details of colour shade, and in other rather unimportant details.

'The area over which a given soil profile prevails in the mature soil is a soil province in the true sense of that word, though it need not consist of one continuous area. On the other hand, it may consist of a number of detached areas.

'Associated with each mature soil within a given soil province there are a varying number of soils in various stages of immature development and certain others in past mature

stages of development. In these the profiles may vary considerably from that of the standard or mature soil. For example, a soil in association with a given mature soil may be so young as to have no true soil profile features whatever, being nothing more than soil material recently accumulated. Freshly laid alluvium may serve as an illustration. Another soil may have developed a surface profile in part or completely with parent geological material underlying it at shallow depth. In still other cases two or more of the upper horizons may have developed. In all cases, except a few of rare occurrence, the horizons developed at any one stage assume the general characteristics of the corresponding horizons of the mature profile. In extreme cases, however, the parent rock may be of such a nature that the surface horizon may be, when first developed, entirely unlike the surface horizon of the mature soil and may remain unlike it through a long period of time.

'Each varying soil profile associated with a given mature profile to whatever stage in development it may be due or whatever variation in character of parent material may have produced its variations, constitutes a distinct kind or, as we designate it, series of soils and the whole group of soils consisting of the mature and its related and associated immature soils constitutes what could be designated as a soil family.'

Since Dr. Marbut wrote the foregoing, mapping and classification of soils has advanced a great deal, and though for obvious reasons the Soil Map of America is still being prepared very much as it was some time ago, the field note-book is very much more comprehensive. The classification of the American Soils by the now generally accepted World Group System is dealt with in great detail in the *Atlas of American Agriculture*, Part III, 'Soils of the United States', C. F. Marbut, 1935, on page 14 of which he produces the following table:

C. F. MARBUT'S CLASSIFICATION OF THE SOILS OF THE U.S.A.

Category VI.	Pedalfers (VI–1)	Pedocals (VI–2)
Category V.	Soils from mechanically comminuted materials Soils from siallitic decomposition products Soils from allitic decomposition products	Soils from mechanically comminuted materials
Category IV.	Tundra Podsols Grey brown podsolitic soils Red soils Yellow soils Prairie soils Lateritic soils Laterite soils	Chernozems Dark Brown soils Brown soils Grey soils Pedocalic soils of Arctic and Tropical regions
Category III.	Groups of mature but related soil series Swamp soils Gley soils Rendzinas Alluvial soils Immature soils on slopes Salty soils Alkali soils Peat soils	Groups of mature but related soil series Swamp soils Gley soils Rendzinas Alluvial soils Immature soils on slopes Salty soils Alkali soils Peat soils
Category II.	Soil Series	Soil Series
Category I.	Soil Units or Types	Soil Units or Types

The categories are referred as follows:

Category VI. Solum Composition Groups.
V. Inorganic Colloid Composition Groups.
IV. Broad Environment Groups [Great Soil Groups].
III. Local Environment Groups [Family Groups].
II. Soil Series Groups.
I. Soil Units.

The English System of Series Classification and Mapping

The English Soil Survey system, originally adapted from the American system in 1925, has steadily developed along lines more suitable to English conditions. The unit of classification is similar to the American unit and is termed the Soil Series. It is defined as follows:

'Soils with similar profiles derived from similar materials under similar conditions of development are conveniently grouped together as Series.' (Robinson, G. W., in *Soils*, 1933.)

The determination of Series is based upon the examination of the soil profile both in its natural environment and in the laboratory. A sub-unit of classification also similar to the American sub-unit and known as the Soil Type is also used and is based upon the mechanical composition (i.e. texture) of either the top 9 inches of the soil or to the limits of the depth of the topmost horizon. The system, though controlled in the main by a certain ritual in procedure, is at the same time capable of some elasticity in its application to special locality factors, so that surveyors, though all obtaining the same kind of data, are allowed a certain latitude in the explanation of their facts in their maps and memoirs.

The general data by which the Series are described are similar to, but not identical with, those in use in America, i.e.

1. Locality Factors.
2. Parent Material (English modification).

3. Topography.
4. Drainage (water relationship, rainfall, &c.).
5. Vegetation.
6. Profile.

The interpretation, however, is specifically applicable to English agricultural conditions. The great difference between the two systems lies in the fact that while much of the American Survey is of a reconnaissance nature and is undertaken for the development of 'new' land, the English system deals in greater detail with material much of which has been under some system of utilization for many hundreds of years. The manner in which the field-man collects his data does not differ radically from the main principles laid down in this book, though it must be remembered that while the book is written to cover contingencies arising both at home and abroad, much of it may be regarded as redundant when reviewing the conditions existing in England. The most important factors in soil-forming processes in England, as in temperate maritime zones in general, are primarily the lithological nature of the parent material, and secondly the water régime of the soil mass, so that the basis of the English Survey is the geology and drainage. To carry out his work, therefore, the field-man must first familiarize himself with the geology of his area. He is able readily to do this from a study of the excellent and detailed maps of H.M. Geological Survey and the accompanying memoirs where such exist. His field equipment consists of spade, auger, indicators, acid, and his mapping outfit. If he is also sampling, then he must carry a rucksack

with bags or cartons as well. As stated previously, the mapping unit is the 'field slip', i.e. the north to south bisected quarter sheet of the 6-inch Ordnance Survey, while his finished or 'Standard' map is the whole or quarter sheet of the same scale. In respect of the scale the English Soil Survey aims at being the most accurate survey in existence ('Bonität Scala' maps being of course excluded). On the plain field slip are marked the field boundaries and contours so that much of the work in location finding, site determination, and ground survey is already done for him. With the geological data he is in the position to commence a detailed survey almost as soon as he enters his area. In his field notebook he may already have been able to record the general data for items I–IV, but he must be prepared to add further details obtainable on closer inspection of the site (history, crops, rotations, manuring, management, &c.). Items V and VI can only be determined in the field. In most cases the auger is used to obtain a general idea of the series, while the spade is mainly used for the preparation of inspection pits representative of the series after its preliminary definition. This practice is the result of experience and is reasonable in the circumstances, because in Great Britain fairly large tracts of country may belong to the same series but are worked with differing degrees of skill in husbandry. These differences must first be balanced up before the series can be defined from the data of the generalized profile which is the mean of many auger tests. The site for the recorded profile pit may then be deduced. Augering is merely a matter of turning the auger

gently into the soil to some arbitrary distance (usually 6 inches), feeling and listening carefully the while for evidence of peculiarities in stoniness, texture, and constitution; when the auger is withdrawn the adhering sample is examined for colour, texture, humus, moisture, consistence, carbonates, &c., and records are made from time to time. The map is marked with a very faint dot and numbered accordingly. The survey then proceeds much on the lines as laid down for 'Open Country Survey' (p. 150), when, by trial and error of bracketing, the series and type boundaries may be run down to an accurate limit. As he proceeds from field to field (the field is a useful unit for location-finding since the English surveyor does not usually use a chain and level) over a uniform area, he links replicate borings at intervals by means of a faint line on the map, so, . When boundaries are found they are sketched in a little more heavily and the dots and lines may be erased. Many experienced field-men are able to sketch in a few yards in advance a conjectured boundary and then walk on to it and prove it correct. This eye-sketching or field-sense comes from the observation of locality factors and is an extremely useful accomplishment to possess during the preliminary definition, and should be practised whenever opportunity arises. During map-making various items relative to the series are written in as they are observed by the use of symbols. The colouring of the map to represent Series and Type may be washed in on the field slip but is usually left until the preparation of the standard. Some field-men may prefer to use crayons as well as symbols during field work.

The following list of colours and symbols are available for use in general mapping:

*Series.** The Series are coloured on the map as nearly representative as possible of the colours of the Solid Geological material from which the Parent Material Groups are derived. On the area thus coloured is also placed a symbol which denotes the soil Series as well as indicating its relation: (*a*) with the Parent Material Group, and (*b*) its position relative to other Series in the same group.

Thus the 'P.M. Group 7, clays, calcareous, subgroup, grey', would comprise any of the clays of the Lower Lias, Oxford, Kimmeridge, or Gault. The Lower Lias clay, however, gives rise at least to three distinct Series of soils which have been designated the Evesham (g^1), Charlton Bank (g^4), and Chadbury Series (g^3). They would be shown on the map by the symbols g^1 g^4 g^3 respectively, while the colours would be variants of the intensity of the same yellow brown colour. (g^1 g^2 g^3 must not be confused with the Lower, Middle, and Upper Lias Series.) The Worcester Series is found on the Keuper Marl—P.M. Group 9, Red Marl, symbol c^1.

The elaboration of this system is not yet complete, but there are sufficient data on which to work for the time being.

Type. The Type is represented by outlining the area by a thin coloured border on the already coloured Series. Thus areas of the heavy loam type of the

* *Suggested Scheme for Colouring and Use of Symbols on Soil Survey Maps*, W. M. Davies and G. Owen. Paper No. 37, Soil Survey Conference, England, 1933.

Evesham or Worcester Series would be enclosed by a thin band around their respective Type areas. In addition to the colour, another symbol is added to the already existing g^1 to now read $g^1{}_{Lb}$. The usual colours and symbols used in this system are as follows:

Sa	light sand	red	Contè	Crayon	No.	5
Sb	heavy ,,	orange	,,	,,	,,	7
La	sandy loam	yellow	,,	,,	,,	11
Lm	Loam	pale green	,,	,,	,,	21
Lb	heavy loam	dark green	,,	,,	,,	28
Za	light silt	pale blue	,,	,,	,,	29
Zm	silt	dark blue	,,	,,	,,	30
Zb	clay silt	purple	,,	,,	,,	40
C	clay	Vandyke brown	,,	,,	,,	45
Peaty used adjectivally		light brown	,,	,,	,,	8

Surface character.

Flat	—+— or left blank
Undulating	∿∿
Slight slope	⟶ head down hill
Steep slope	+⟶ ,, ,, ,,
Very steep slope	++⟶ ,, ,, ,,
Broken and irregular	ʌʌʌʌ

(The length of arrow indicates the area concerned. Degree of slope not usually demanded.)

Stones.

Stoneless or nearly so	○
Slightly stony not interfering with cultivation .	①
Very stony interfering with cultivation . .	②
Occasional boulders	③
Live rock exposed	④
Rock dominant	⑤

Size and shape not usually demanded, though 'nature of' is usually recorded in notebook.

Colour. (Red R.), (White W.), (Yellow Y.), (Brown B.), (Grey G.), (Black Bk.), (Blue Bl.), (Green Gn.), (light lt.), (dark dk.).

Water Data.

Seasonal drought	α
Seasonal wetness	β
Permanent wetness (water-table too high)	γ
Liable to flood (River)	δ
Springs	ϵ
Irrigated (meadow not warp)	Ir.
Straightforward drainage is possible	$\frown$
,, ,, is not possible	$\smile$

Spot Points.

Profile Pit	$\triangle 1$	
Sample spot	$\boxed{1}$	
Special note	$\diamond 1$	i.e. monolith, P.M. exposure, &c.

Thus by making use of all the symbols a Soil Type could be described on a map in the following manner:

Series	Worcester (P.M.G. = C)	also in colour
Type	Worcester heavy loam $C^1{}_{Lb}$	

Flat site	$C^1{}_{Lb}+$
Stoneless	$C^1{}_{Lb}+O$
Colour (brown)	$C^1{}_{Lb}+OB$
Water (seasonal wet)	$C^1{}_{Lb}+OB\beta$
Drainage possible	$C^1{}_{Lb}+OB\beta\frown$

A specimen layout of the final description of a Series is given below:

**Conway Series (Leaton Knolls) Meadow Soil*

Parent Material	Silt Clay (P.M. Group 11)
Geology	Alluvium (River Severn) (Derived from Paleozoic mudstones)

* Third Report, English Soil Survey Conference, 1937, p. 26.

Topography . Flat to gently undulating
Drainage . . Impeded, somewhat variable
Vegetation . . Grassland.
Profile:

0–10 in. Pale greyish-brown *medium* to *heavy clay silt loam*. Stoneless. Slightly rusty mottlings tending to follow grass roots. Rather compact. Crumbling with pressure.

10–16 in. Pale grey *heavy silt loam* with orange and some black mottlings. Compact.

16 in.+ Similar material with more pale grey and black mottlings. Less pronounced orange mottling.

Types in the series. *Medium silt loam* and *heavy silt loam*.

Analytical Data

		0–10 in.	*10–16 in.*	*Below 16 in.*
Stones, Fine gravel	Per cent. . .	1·0	..	..
Coarse sand	,, . .	5·7	2·2	1·2
Fine sand	,, . .	13·2	8·7	4·4
Silt	,, . .	35·0	40·8	44·5
Clay	,, . .	35·0	43·3	43·7
$CaCO_3$	,, . .	1·02	0·23	0·05
Loss on solution	,, . .	3·10	1·50	1·63
Moisture	,, . .	2·10	2·20	2·05
Loss on ignition	,, . .	9·75	6·45	6·25
Exchangeable CaO	,, . .	Free Carbonates	..	..
pH	,, . .	7·85	7·90	7·95
Composition of the clay fraction:				
SiO_2	per cent.	47·30	47·39	47·76
Fe_2O_3	,, ...	9·14	10·04	8·35
Al_2O_3	,, ...	32·72	33·77	32·75
TiO_2	,, ...	0·87	0·92	0·90
SiO_2/R_2O_3	,, ...	2·08	2·00	2·13
SiO_2/Al_2O_3	,, ...	2·45	2·35	2·47
SiO_2/Fe_2O_3	,, ...	13·77	12·59	15·21

English Regional Survey

The following description has been taken from notes which have been supplied by R. Bourne, who is the author of numerous papers on this subject. The general principles have much in common with the Landscape System, though Bourne brings out the importance of the 'age of site' and its relation to the geomorphological and ecological characteristics with a greater emphasis than is usual in other regional surveys.

The execution of a regional soil survey demands a preliminary review of the geological history and physiographical development of the area. The alternation of land and sea phases, the chronology of igneous activity and earth movements, and the results of successive erosion cycles must be studied. In particular, the possibility has to be determined of relics of former land-forms forming parts of the present land surface. In fact, the relative ages of different sites should, as far as possible, be ascertained.

Similarly, an historical review is involved of the climatic and associated vegetational changes which can possibly have influenced the soil processes on any of the sites in the area. Clearly the period over which this review should extend is the age of the oldest sites which survive. Parallel studies are required of human settlement and land utilization, climatic changes, and vegetation succession. Special attention should be paid to localities in which the vegetation succession, through one or more climatic phases, may have escaped deflection in the absence of human interference In fact, the possibility must be considered of the

preservation of fossil soils and vegetation relics of climatic phases previous to the present.

To establish and assemble such 'facts' as have been referred to in the preceding paragraphs, a surveyor should study not only all relevant and available literature but undertake a rapid reconnaissance survey with special reference to the topography, geology, micro-relief, soil, botany, and general geography of the area. Undoubtedly the best procedure is to traverse the area at wide intervals more or less at right angles to the drainage systems. If a geological map is available, this should be studied and as many geological exposures as possible examined. In their neighbourhood, soil profiles should be exposed and compared with the geological data obtained. Traces of older arable cultivation should everywhere be looked for, and any localities which would appear to have escaped cultivation altogether should be thoroughly studied. Woodlands especially call for close examination. In these it is generally desirable to expose and describe a set of soil profiles carefully located according to the micro-relief or other evidence of soil differences. A rapid survey of the ground vegetation not only in woodlands but in waste lands is also frequently desirable and enlightening. If air photographs are available, on either a large or a small scale, they are invaluable at this stage of the work in drawing the attention of the surveyor to many phenomena difficult to see from the ground, in giving him a perspective view of many surface effects, and in reducing to an absolute minimum the actual measurements necessary for purposes of plotting the results on maps.

Proceeding systematically in this manner, a competent surveyor soon comes to distinguish between effects due to local site or soil conditions and those attributed to human interference whether destructive or constructive. He rapidly learns to recognize soils of different ages, to draw a distinction between temporary and permanent differences in soils, and to appreciate the reasons for these differences. As he progresses, he comes to understand the general structure of the region he is traversing and, when he reaches the boundary of another region, he often realizes at once that, thenceforward, he has to deal with a different set of conditions, sites, or soils. Nevertheless, he should carry on, re-orientating his line from time to time, as circumstances may dictate, and studying the structure, &c., of each region encountered. Indeed, a comparative study of regions often throws as much light on the whole problem of regional soil survey as a comparison of individual soils does on the reasons for their differences.

When a surveyor has adequately traversed his area, he should be in a position to classify the soils encountered according to their 'series' and to list the series which occur in each region both in their topographic or geological sequence and in order of their importance judged by the frequency of their occurrence. Assuming that he has the necessary botanical, agricultural, and forestry knowledge, he should also be able not only to list the uses to which each series have actually been put, region by region, but also to indicate the relative successes and failures in usage, the reasons for the same, and the possibilities of correcting mistakes.

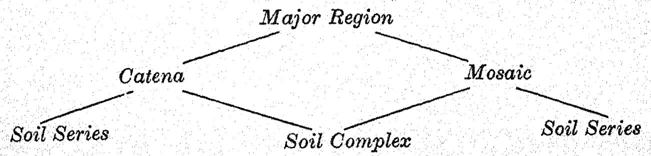
Finally, he should have a clear idea of the remaining problem of delimiting regions, knowing which boundaries are marked by topographic features, which are generally defined by vegetation or usage, and those which can only be fixed by soil boring or other soil examination.

At this juncture, where detailed geological and topographical maps are in existence, it should generally be possible to delimit on maps several of the regional boundaries, some finally and some provisionally. Where air photographs are also available, particularly small-scale air photographs, it may be possible to identify many other boundaries with considerable accuracy without proceeding to the field, more especially when the contact prints are examined in a stereoscope. The importance of taking this step lies in the time which can be saved by planning an itinerary in advance of the actual boundary identification on the ground. Since large areas have to be covered at this stage of the work, time is a very important consideration. In actual procedure it is often sufficient to verify boundaries at accessible points, completing the regional map by interpolation. There are, however, cases where the boundary must be traversed; for instance, where a somewhat tortuous soil boundary exists not coincident with a topographic feature nor determinable through reading the vegetation from any distance.

Thus a regional soil or catena survey, while it involves the identification and classification of all the soil series which occur in any area, can be completed in advance of a detailed soil survey and provides a

perspective view of the distributional grouping of soil series over a countryside. By throwing light on the evolution of the existing soil series and establishing the reasons for divergence about their means, a regional soil survey is in fact essential to the classification of soil series and should, logically, precede the detailed soil survey. Finally, by identifying distinct combinations of climate, topography, and geology, or soil catenas, and delimiting them on maps, a regional soil survey furnishes the student of ecology, whether plant or animal ecology, including the ecology of man, with a physical and historical background essential to the proper understanding of present surface effects and of the problem of planning for the future.

The relationship between the Regional survey and the Soil Series is shown in the following scheme:



Soil Complex.

A Complex is an association of Series where the soil varies so much that boundaries of the individual Series and Types cannot be delimited without further intensive survey on a larger scale. Such boundaries can be defined on the new Ordnance Survey Map of 1/20,000 whereon 5-feet contours are shown.

Soil Catena.

A Catena is a sequence of repetitive Soil Series which recurs in a manner dependent upon topographical and/or geological features.

Soil Mosaic.

A Mosaic is a sequence of Soil Series which occurs in a manner *not* dependent upon topographical and/or geological features.

Major Region.

A Region is an area of geographical significance made up of Catenas, Mosaics, Series, and Complexes. The Vale of the White Horse or the Vale of Evesham could be described as Major Regions.

In addition to those few methods of survey which have just been discussed, there are many others which could be quoted to the extent of doubling the size of this publication. In almost every country there exists some specific system of soil study either for the reclamation of naturally unproductive soils into a state of valuable productivity or for the more modern utilization of already productive soils. If the writer has contributed anything towards helping the beginner to observe and record what is there in the soil to be seen, this little work will have served some small purpose.

APPENDIX I

SOIL SURVEY OF ENGLAND AND WALES

FIELD HANDBOOK

PREFACE

A VALID system of classification is an indispensable basis for soil survey. Such a system must be based on accurate and, so far as possible, objective observations in the field. It has long been felt that published profile data have been unsatisfactory through lack of uniformity in presentation and of precision in the terms used. The problem has been under active discussion among soil surveyors in this country and Mr. Clarke has taken a leading part in evolving a satisfactory scheme for the recording of soil profile data. The present handbook, with its accompanying sheets, is the outcome of his work, and will be used in future in the Soil Survey of England and Wales. The method may be equally recommended for the recording of soil data by foresters, ecologists, and others. Although devised in the first instance for British conditions it should find ready acceptance by workers overseas.

G. W. ROBINSON,
Director of Soil Survey for England and Wales.

BANGOR, 1940.

Printed in Great Britain

FOREWORD

SINCE the field sheet is only required for the recording of the series *standard pit*, the possibility of having to record more than ten pits in any one day is unlikely. The use of a large field book is therefore a waste of transport, while unused sheets may become soiled and wasted. The specimen field sheet shown is carried in a stiff card container 14″ wide × 11″ deep, folding to 7″ × 11″ so that it can, if necessary, be carried in the ordinary field mapping-case. The sheet is retained in position by one or more strips of elastic, movable to facilitate writing. The right-hand edge of the slip is used for subsequent filing. The case may have two pockets, one containing clean sheets, the other used sheets, by this method but one sheet at a time is exposed to handling. On the inside of each cover is a 'reminder' list containing abbreviated notes of various symbols and definitions abstracted from the fuller notes contained in the field handbook. Most of the material for the questionnaire is drawn from G. R. Clarke's *Study of the Soil in the Field*, 2nd edition (Oxford University Press), while the remainder has been more recently obtained from the U.S.A. Department of Agriculture and the various Soil Surveyors' Sub-Committee reports. It is not suggested that the final and fair copy of a profile description should take the form of the field sheet. It is suggested, rather, that final descriptions should all be in words and laid out much as they are in the present S.S. Conference Reports, i.e. each horizon fully described in a series of sentences written across a page.

THE SOIL DESCRIPTION

EACH item on the sheet is to be filled in according to the following fixed definitions so that profile sheets can be read by other workers without risk of misrepresentation.

1. Profile Number. An obvious item.

Date. The date is important since profiles do, in certain circumstances, vary with time of year, e.g. B.F. soils under heavy canopy in summer and open canopy in winter.

2. Locality. This must be clearly defined as the locality of the pit itself and not of the series as a whole.

3. Map Reference. The sheet index data and its edition of the 6-inch O.S. map in actual use is to be preferred. Cross indexing by imaginary 1 in. squares (as 17″ N. 21″ E.) serves to fix a point fairly accurately so that by using items 2 and 3 together the exact site may be determined.

4. Series. This applies to the *Series* in which this pit occurs (e.g. Penrhyn).

S.F. 175. **Type.** In Series wherein surface variations, &c., are responsible for numerous *Texture Classes* the specific class to which the description applies must be clearly stated. From this data the *Soil Type* name is obtained (e.g. Penrhyn light loam).

S.S. Conf. paper 39. **5. Genetic Group.** A list of Genetic Groups to which the soil may belong has already been drawn up by the Soil Surveyors' Conference. It is reproduced here so that all relevant matter may be included in one article.

S.F. This refers to page number in *Study of the Soil in the Field*, 2nd edition.

F. DEFINITIONS

I. Soils of the Brown Earth Group.

Three characteristics form the basic definition of the normal Brown Earths:

1. The soil has free drainage throughout the profile.
2. There is no vertical differentiation of silica and sesquioxides in the clay fraction.
3. There is no natural free $CaCO_3$ in the soil horizon.

Other morphological and chemical features may vary. Thus the soil may be of any colour, but this colour is more or less uniform throughout the profile; the degree of acidity may vary widely.

The virgin soils are usually characterized by an accumulation of leaf litter on the surface, which is underlain by mull humus. Under cultivation, the surface is altered, added bases may be present, and to this extent arable soils will differ from the normal Brown Earths.

The Brown Earth group is divided into soils of low base status and soils of high base status. Soils with a high base status are only slightly acid, and become neutral with depth; they are derived from base-rich parent materials. Those of low base status have a tendency to acidity throughout the profile.

Subtypes of the Brown Earth Group (Low bases Pale Brown, High bases Dark Brown).

(*a*) *Creep or Colluvial Soils.* This group is dependent on topography for its development. In morphological and chemical characteristics it is the same as the normal Brown Earth soils.

(*b*) *Brown Earths with Gleyed B and C Horizons.* The soils of this subtype are the same as the normal Brown Earths except for a suggestion of gleying in the lower horizons. This gleying is no more than an occasional bluish or rusty mottling. The effect may be due to rare rises in ground water or to a slight impedance in drainage.

(*c*) *Leached Soils from Calcareous Parent Materials.* These soils are characterized by a red-brown colour and a condition of base unsaturation. They may be quite

acid, and if $CaCO_3$ is present it is in the form of hard lumps. Organic matter is light in colour, but is not necessarily low. Secondary $CaCO_3$ may occur at the base of the B horizon, or in the parent material.

II. Soils of the Podsol Group.

The chief morphological characteristics of normal podsolized soils are:

1. The presence of a bleached (grey) layer under the surface raw humus.
2. The yellow to rusty coloured accumulation layer which follows.

The chemical characteristics are found in the differentiation of the silica and sesquioxides of the clay fraction.

Under cultivation the surface raw humus is absent. Arable soils may show the typical grey and rusty layers, or these may be almost entirely obliterated. All transitions occur, but so long as the clay fraction shows differentiation of the silica and sesquioxides, such soils are included in the podsol group.

Subtypes of the Podsol Group

(*a*) *Slightly to strongly Podsolized Soils* (Pale Red). These depend on the thickness of the bleached horizon.

(*b*) *Concealed Podsols.* The soil has a raw humus surface layer but no bleached layer. The translocation of sesquioxide is proved by the changes in the silica-sesquioxide ratio.

(*c*) *Peaty Podsolized soils* (Dark Red). In these the raw humus has developed into peat. They may vary from a slightly to strongly podsolized condition (for definition of peat see later).

(*d*) *Podsolized Soils with Gleying.* These are essentially podsolized soils in the upper layers, but exhibit signs of impedence by gleying in the B or C horizons.

(*e*) *Truncated Podsols.* Here the surface soil has the characters of a B horizon. Under grass vegetation the iron colours are washed by humus.

III. Soils of the Gley Group.

The characteristic of gleying is the presence of greenish, bluish-grey, rusty or yellowish spots or mottling.

1. *Surface Water Gley Soils* (Pale Blue). In these the excessive water is on the surface and produces gleying in the surface horizons. In the lower horizons gleying progressively decreases or may be absent altogether.

2. *Ground Water Gley Soils* (Dark Blue). The surface of such soils may be dry, at least seasonally and often permanently, with little or no gleying. Gleying is essentially present in the lower layers. This group includes soils with slow percolation, not necessarily occurring only in depressions.

Subtypes of Ground Water Gley Soils

(*a*) *Gley Podsolized Soils* (Pale Green). These soils have a raw humus surface and a bleached A horizon. The B horizon is thin or absent. Gleying occurs below this level.

(*b*) *Peaty Gley Podsolized Soils* (Green). Essentially similar to 'Gley Podsolized Soils' but peat replaces raw humus.

(*c*) *Peaty Gley Soils* (Dark Green). These soils are completely gleyed and carry a peaty surface.

(*d*) *Gley Calcareous Soils* (Grey). These are characterized by a grey colour and a moderately high organic matter content. Calcium carbonate occurs throughout the profile and increases with depth; the soil is base saturated. There is little change in the silica-sesquioxide ratio down the profile. Secondary calcium carbonate often occurs in the form of concretions, especially in the lower layers. Gleying is shown by the presence of bluish, greenish, rusty or yellow spots and mottling.

IV. Soils of the Calcareous Group.

These soils are developed from calcareous parent materials, contain primary calcium carbonate in the soil horizons, and are base saturated.

Subtypes of the Calcareous Group

(*a*) *Grey Calcareous Soils* (Yellow). (Rendzina type.) Under natural vegetation these soils show a very dark surface horizon, a high content of organic matter, and a well-developed crumb structure. There is no differentiation of the silica-sesquioxide ratio down the profile. Calcium carbonate increases in amount with depth

until the parent material is reached. Secondary deposition of calcium carbonate may occur.

Under arable cultivation organic matter is lower, calcium carbonate is higher, and the soils may be pale grey or almost white in colour. Crumb structure is less pronounced.

(*b*) *Red and Brown Calcareous Soils* (Orange). These are formed on hard limestone and do not occur on the chalk. They are shallow, being characterized by a red or brown colour and by the presence of fragmentary calcareous rock. The organic matter content is usually low and the silica-sesquioxide ratio constant throughout the profile. Secondary deposition of calcium carbonate may occur in the parent material.

(*c*) *Calcareous Soils with Gleyed B and C Horizons.* These soils, in the upper layers, are similar to either subtypes (*a*) or (*b*), but show slight gleying in the lower horizons.

V. Soils of the Organic Group (Purple).

The soil character is determined by the presence of twenty or more centimetres of water-logged organic matter, termed Peat. There are two groups:

1. *Basin Peat.* Soligenous in origin, i.e. formed under the influence of excessive or stagnant ground water.
2. *Moss Peat.* Ombrogenous in origin, i.e. formed under the influence of heavy rainfall and low summer temperature.

Basin Peat. The main development forms of this group are as follows:

*a*1. *Fen* (including Carr). This is formed under the influence of calcareous or base-rich ground water. Map Symbol B. Transition phase is Grass-moor, &c.

*a*2. *Raised Moss.* This is ombrogenous as a result of accumulation of 1*a* above ground water level. Map symbol $\frac{M}{B}$.

*b*1. *Acid Low Moor.* This is formed under the influence of drainage from acid or base-poor rock and soils, e.g. podsolized surface or raised moss. Map symbol A.

*b*2. *Raised Moss.* As in *a* (2). Map symbol $\frac{M}{A}$.

Note. Moss peats are predominantly ombrogenous since they develop under conditions of high rainfall on a substratum lying above ground-water level. The ultimate form of these is 'Raised Moss' (Map symbol M) and may develop over any organic soil when it grows above ground-water influence.

Moss peat covering a region is termed 'Blanket Moss' and is to be regarded as climatic in the pedological sense. Map symbol C.

Sub-type of b2. Hill Peat

This is a variety of Blanket Moss formed on hill tops and slopes which varies from the main type in distribution and character and is therefore to be mapped separately as 'Hill Peat'. Map symbol H.

VI. UNDIFFERENTIATED ALLUVIUM GROUP (Ivory).

Owing to the great variety of soils which may be encountered in a comparatively small area of alluvium, some surveyors do not attempt to differentiate them. In such cases the soils are allocated to this group. Where alluvial flats are extensive careful survey will be worth while. In this case the different series identified will be allocated to one of the other five groups.

6. Elevation; Slope; Aspect; Relief (Macro, Micro). S.F. 33. The importance of each and all of these items is dealt with in almost any book dealing with soil genetics and so it will suffice here if we confine ourselves to the data to be recorded.

Elevation. Elevation should be given in feet. O.D.

Slope. Either the degree of slope or the percentage slope may be used. The system of gradients (i.e. $1 \left\{ \begin{matrix} \text{to} \\ \text{in} \end{matrix} \right\} 6$, &c.) is not fool-proof and in most cases can only be determined after the determination of one or other of the former items. The shape of the slope should be described roughly by the use of the following adjectives:

Concave, Convex, Terraced } with Uniform, Irregular } to qualify.

Aspect. If taken to the nearest $22\frac{1}{2}°$ (i.e. 1/16 of the magnetic compass) it should be sufficient for most practical purposes. If the site is unduly exposed to, or sheltered from, prevailing winds, notes should be made of the facts because the agricultural value of the site may be mainly controlled by such factors. If the site is dead level it has no aspect.

Relief. This applies to surface conditions and is generally discussed in terms of macro and micro relief. Ridge and furrow land, flood plains, recent silt deposits, marshland, basin, &c., are used for this item.

S.F. 37. **7. Drainage.** Space is reserved for two drainage descriptions.

(*a*) **Profile.** *The top space* is allotted for the percolation of water *through* the soil and is classified as:

1. Excessive. Loss of bases probable.
2. Free. Satisfactory percolation and retention.
3. Imperfect. Some gleying but not anaerobic.
4. Impeded. Stagnant groundwater, waterlogging.
5. Surface water run-off exceeds percolation. This may be caused by the topography, the nature of the soil mass, or by a combination of circumstances. Use may be made of symbols.

   S.R. +++ Intense, some erosion probable.
   ++ Definite, but no erosion likely to occur.
   + Local run-off.

S.F. 181. (*b*) **Site.** The lower space defines the character of the site and use is made of the Greek symbols recom-

mended at the S.S. Conference, Leeds, 1926, with the addition of the letter S. for generally *satisfactory* conditions.

S. Satisfactory
α. Seasonal drought
β. Seasonal wetness
γ. Permanent wetness
δ. Liable to river flood
ε. Springs
Ir. Irrigated
Wp. Warp
Easily drained (Local scheme) ⌒
Difficult to drain (Regional scheme) ◡

8. Parent Material. The P.M. is the mineral matter (C horizon) from which the soil itself is made. This should not be confused with the parent rock which gives rise to the parent material; as some difference of opinion exists as to the best method of recording this information it may be better to record the observed facts under two heads, namely, S.F. 27.

1. The parent rock from which the C horizon is derived, using the classification given below, and
2. The mode of formation, e.g. weathering *in situ*, till, colluvium, &c. Space is allowed in order to allow of a clear definition. It would be better to enter the data under head (1) verbally, but the group number could also be given, e.g. Norite 3 or Red Marl 9. Where possible the stratigraphy should be given, e.g. Millstone Grit, Keuper Marl, &c., and could be inserted as a separate item.

List of Parent Rock Materials (1936)

Group No.	
1	Acid Igneous Rocks
2	Basic Igneous Rocks
3	Ultra basic Igneous Rocks
4	Basic Tuffaceous Shale
5	Schist and Gneiss
6	Slate and Hard Shale
7	Clay and Clay Shales, Calcareous
8	Clay and Clay Shale, Non-calcareous
9	Red Clay, Calcareous
10	Red Clay, Non-calcareous
11	Silt-clay
12	Sand, Calcareous
13	Sand, Non-calcareous
14	Sandstone, Calcareous
15	Sandstone, Non-calcareous
16	Sandstone, Felspathic, Non-calcareous
17	Glauconitic Sand
18	Hard Limestone
19	Soft Limestone
20	Chalk
21	Brickearth
22	Peat
23	Complex drifts:
	(*a*) Clay with Flint
	(*b*) Red drifts
	(*c*) Grey drifts

Symbols for Peat Soils:

Basin Peat { Basic B.
Acid A.

Moss Peat { Blanket Moss. C.
Sub-type-Hill Peat. H.
Raised Moss M.

Raised Moss develops either on other peat or on other soil types.

Raised Moss Peat developing on Basic Basin Peat—$\frac{M}{B}$.

Raised Moss Peat developing on Acid Basin Peat—$\frac{M}{A}$.

9. Vegetation. This should include the Plant Formation and Plant Association. Terms such as 'grass' or 'arable' are to be deprecated. Unless proper notes are made of this item the profile examination and its record must be practically useless. In addition to the foregoing, notes on *density* of *population*, *canopy*, &c., are of great practical value. S.F. 42.

10. Mapping Index Data. This item refers to the recommendation of the S.S.C. Sub-Committee on colouring and ample space is allowed for its compilation in detail as required in the field.

Weather Conditions, &c. Since the weather conditions prevailing for some time prior to sampling may be responsible for the production of a set of profile characteristics later found to be abnormal, the need for a proper consideration of this item is obvious. The terms normal or abnormal with the addition of the qualifying data will, however, generally be found sufficient, e.g. 'four very wet days, now drying fast in East wind'. Where possible to obtain, the notes should include the distribution of rainfall and the main variation in maximum and minimum temperatures.

The Examination and Recording of the Soil Profile Pit.

Column I. (Depth and Clarity of Horizon and Layers.)

Layers. The designations A, B, and C are not always S.F. 59.

definable until after analysis. For field work, therefore, the term should be *layer* and the layers should be recorded from the top downward, e.g. Layer I, Layer II, &c. In the case of humus or leaf-littered soils the classification of the O.M. into Hesselman's F and H Layers will usually suffice for most purposes, but the classification of Romell and Bornebusch (S.F. 75) must be borne in mind when dealing with forestry problems. The surface layers of the soil proper should always be described according to their origin or use, e.g. Ploughed layer, Sod layer, Heath layer, &c. The layers are subsequently described in detail according to the questionnaire.

Depth. The depth of each layer is recorded in inches and scaled in the space provided.

Clarity. The clarity with which the boundaries between layers are defined are recorded conventionally by lines drawn at the appropriate position in Column I.

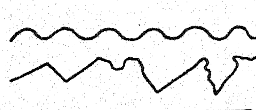
Sharply defined, changes within 3 cm. (1″) a line. ————

Clearly defined, changes within not more than 5 cm. (2″) dashes. - - - - -

Merging defined, changes slowly over wide range, dots. :::::::

These lines may also describe the general run of the layer:

Wavy
Irregular
Smooth



Column II (Colour).

If colour cards or any matching devices are used, the appropriate remarks will of course be made. In ordinary

field work, however, only the minimum number of colours consistent with a sound description should be used. The following colour description is taken from C. C. Nikiforoff of the U.S.A. Department of Agriculture (now used by the U.S. Bureau of Soils). It differs but little from the old S.S. Conference use of the Robinson monomark system but allows of a little more descriptive detail.

The principal colours of the soils and their designations are as follows:

Black	Bk.
Grey	Gr.
Brown	Br.
Yellow	Ye.
Red	Rd.
[1]Orange	Or.

In most cases, these colours are not pure but are modified by some particular tint. The following tints are in common use in soil descriptions:

Ashy	a—
Olive	o—
Greyish	g—
Brownish	b—
Pinkish	p—
Reddish	r—
Yellowish	y—

The letter symbols of these modifying 'tints' should be used in combination with the symbol of the principal colour in the same order as the words are used, thus, aGr. = ashy-grey; rBr. = reddish-brown. These compare with the designations of soil textures, such as sandy loam and silty clay.

[1] Orange is not used in the U.S.A. but is used in England.

Each of the principal colours, with the exception of black, may have several grades, according to the intensiveness or depth of colour. The five grades are designated as follows:

Very light	1
Light	2
Medium	3
Dark	4
Very dark	5

Samples of the complete designations of soil colour appear as:

oGr1 = very light olive-grey colour.
rBr4 = dark reddish-brown colour.
bGr5 = very dark brownish-grey colour.

Not infrequently the brown, red, and yellow colours are described as dull or bright (warm or rich). These terms may be designated as — for dull and + for the bright or rich. For example: — gBr4 = dull dark greyish-brown, or

$$+\,\mathrm{rBr4} = \left.\begin{matrix}\text{Bright}\\ \text{Warm}\\ \text{Rich}\end{matrix}\right\}\text{dark reddish-brown, \&c.}$$

In addition to the colour which may be put into the column either as a symbol or in words, note must be made of the disposition of the colour or colours in multicoloured layers. The following terms have been found adequate for any soils so far recorded:

Self	Speckled	Streaked	Rippled
Waved	Banded	Cloudy	Mottled

Column III (Texture).

S.F. 180. The English system of nomenclature remains unaltered.

	Light Sand	Heavy Sand	Light Loam	Medium Loam	Heavy Loam
Class . .	Sa.	Sb.	La.	Lm.	Lb.
Conté Crayon for mapping	5 Red	7 Orange	11 Yellow	21 Pale green	28 Dark green

	Light Silt	Silt	Clay Silt	Clay	Peat
Class . .	Za.	Zm.	Zb.	C.	P.
Conté Crayon for mapping	29 Pale blue	30 Dark blue	40 Purple	45 Vandyke brown	8 Light brown

Peaty may be used adjectivally.

Column IV (Mineral Skeleton. Stones).

This item is concerned mainly with the chemical nature, quantity, size and shape of *stones*. The chemical nature is described generally adjectivally, e.g. quartz pebbles or granitic gravel, &c.

Quantity

Symbol		*Abbreviations*
o	Stoneless or nearly so.	N. None.
(1)	Slightly stony, not to interfere with cultivation.	N.F. Not frequent.
(2)	Very stony, enough to interfere with cultivation.	M. Many.
(3)	Occasional boulders.	F.B. Few boulders.
(4)	Live rock exposed	R. Rock.
(5)	Rock dominant.	R.D. Rock dominant.

Size. The size is always given by name (e.g. coarse gravel).

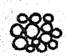
Gravel	C. gravel	V. small stones	Small stones	Medium stones	Large stones	Boulders
$\frac{1}{8}''$–$\frac{1}{4}''$	$\frac{1}{4}''$–$\frac{1}{2}''$	$\frac{1}{2}''$–1″	1″–2″	2″–4″	4″–8″	>8″

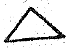
Shape.

Angular	Sub-angular	Rounded	Shaley	Tabular

Column V (Structure).

There are many systems for the classification of soil structure, but in the field and in the face of a newly made pit good structural features are not always evident. The Russians describe structure as the size and shape of soil aggregates, whereas the Americans sometimes bring in the constitution as well. At the Stenigot meeting of the S.S.C. 1939 it was decided not to merge the two. The following list is the minimum possible adequately to describe the soil aggregates of English soils.

Symbol	*Name*	*Definition*
	Crumb	Roughly rounded. *Well*-defined pore spaces in aggregate
	Nutty	Roughly rounded, but larger. *Well*-defined pore spaces in aggregate
	Cloddy	Conchoidal (Starchy). *Ill*-defined pore spaces in aggregate
	Granular	*Solid* rounded (Shot-like). *Ill*-defined pore spaces in aggregate
	Laminated	Plate-like
	Prismatic	May sometimes be jointed columns

Symbol	Name	Definition
	Columnar	May sometimes be joined up prisms
	Pyramidal	The peculiar structure of gleyed clays
	Structureless	No aggregation of single particles when shaken through hands (loose sands, &c.)

The *size* of the aggregates should be noted in respect to the main axes. Sketched in symbols are always of help in the field. To draw up a list of names to describe size as well as shape only makes the scheme more unwieldy.

Column VI (Constitution).

This term is generally accepted as defining the character of the interstitial spaces (between aggregates) and is described by two main reactions to the senses.

Porosity. This is a *visible* characteristic. When a profile is examined by eye, small holes, cracks, and fissures are apparent. These lend themselves to a simple classification of four:

1. Porous. Soils with many very small holes, 1–3 mm.
2. Fissured. Definite cracks, usually vertical.
3. Spongy. Rounded holes, various sizes but usually >3 mm.
4. Closed. No cracks or spaces apparent.

The terms 'fine', 'coarse', 'very', and 'slightly' are very important as qualifying expressions.

Consistency. This is a *handling* characteristic. The manner in which a soil handles, bores or digs is very important.

1. Loose. Particles fall off auger or run through fingers.
2. Compact. Good 'bite' with auger, digs clean and well.
3. Indurated. Auger 'grinds' and spins. Pick needed to dig.
4. Friable. Auger comes up loosely packed. Digs nicely.
5. Tenacious. Auger 'sucks' and comes up full. Spade clogs.
6. Mellow. Bores and digs pleasantly. Ideal tilth, and implies presence of humus.

S.F. 71. *Column VII* (Organic Matter).

The nature and distribution of the organic matter in the soil mass proper are differentiated into two main groups.

1. *Intimate humus.*
2. *Mechanical organic matter.*

Intimate humus is a dark-coloured substance dispersed mainly throughout the A and B horizons in English soils. It reacts with H_2O_2. It appears as bands, patches, or streaks.

Mechanical O.M. refers to unhumified or partially humified matter *in* the soil mass brought into any horizon by the dying of roots, downwash into old root- or worm-channels, or by the mechanical mixing produced by cultivation or animal activity. This is a very important item since the quantity, distribution, and nature of the organic matter greatly influence the general properties of the soil. Fairly full written descriptions are usually considered the best way of

recording this item. Surface organic matter, peats, &c., are not generally included in this classification, they belong more properly to the Ao horizon, i.e. the layer above the soil mass proper, and are classified either as Hesselman layers (F and H) or Fraser's Peats (S.F. 77).

Column VIII (Roots).

Roots may be used as a valuable criterion of drainage, aeration, and general health of the soil. Notes should include references to the—

Quantity . .	Few, many, &c.
Size . . .	Large, small, &c.
Health . .	Dead, alive, healthy, &c.
Age . . .	Young, old, of past or present surface vegetation, &c.
Shape, or Nature.	Turfy, fibrous, distorted, free growth, &c.

Sketches of the roots greatly help in the general write up later and clarify description.

Column IX (Water Condition).

This item concerns all reactions of the soil water, including the quantity, movement, and character as they affect each particular layer. The height of the water-table and its fluctuations, whether it is stagnant or flowing, &c. All are worthy of description. Evidence of *gleying* should also be noted in this column. S.F. 185 and 119.

The degree of saturation of the soil mass should also

be determined by eye and by touch in each layer. Kreybig's scale of moisture standards is a sound one.

o	Air dry.
+	Just moist.
++	Moist, colour changes on more wetting.
+++	Wet, colour does not change on more wetting.
++++	Waterlogged, i.e. water seeps and oozes.

Column X (Sec. Chemicals and Minerals).

Primarily, this item records the presence of secondary (i.e. *pedological*) chemicals such as nodules of carbonates, 'earth hearts' or crystals of sulphates, &c. Care should also be taken to record such substances as limonitic, ochreous, and manganese compounds. Such substances are frequently important indices of the general soil conditions. In addition, note should be made of the presence of such minerals as glauconite, micas, &c., which though not of secondary formation, may serve as important factors in the classification of the Series.

The condition and disposition of these substances should also be described, i.e. concretions, streaks, bands, dendrites, &c. Special care should be taken to spot any evidence of such characteristic pedogenic processes as podsolization, salination, hydromorphism, &c.

Column XI (Fauna).

S.F. 123. Evidence of the presence and activity of ants, worms, moles, rabbits, &c., should be noted particularly with reference to the aeration and drainage of the layers in which they may operate.

Column XII (Carbonates).

The soil should be tested with acid and the amount of carbonate present roughly estimated by the violence of the reaction. Effort should be made to determine whether the reaction is due to relic parent rock, added lime, or secondary accumulation. Kreybig makes use of four categories. S.F. 68.

o	Nil.			
+	Very little fizz .	<5	per cent.	approximately.
++	Much . .	>5	,,	,,
+++	Violent . .	>10	,,	,,

T. Wallace has suggested that to avoid the difficulties attending the use of acid in the field an equally good reaction can be obtained by the use of sod. acid sulphate and common salt. Equal quantities of each of the dry substances are dissolved in a little water, when the resulting solution will react upon carbonates very much the same as will a dilute solution of hydrochloric acid.

Column XIII (pH).

Since the samples will be tested for pH in the subsequent laboratory investigation, accuracy in this determination in the field appears to be somewhat redundant. It must rest with the field man as to how much he depends upon this figure for any of his field descriptions. The determination of a rough pH to confirm a suspected translocation of ions from one layer to another is, however, frequently very useful, and for this reason, if none other, the column serves its purpose.

General Notes.

The need for data regarding the *Series* other than the pit and site description is obvious. The space provided is probably inadequate but there is the whole of the back of the sheet available for a good sound write up. Field men should endeavour to obtain enough material to enable analytical results to be properly interpreted. Most field men have this knowledge from experience, but it is rarely written down for the use of the laboratory staff, i.e. Advisory Chemists, &c., who have to interpret results and write reports.

REMINDER (PROFILE)

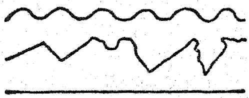
I. Layers.

Sharply	1"	Line.	———
Clearly	1"–2"	Dashes.	- - - - -
Merging	Wide range.	Dots.	. . . .

Wavy.

Irregular.

Smooth.



II. Colour.

Black	Bk.	Ashy	a.	Very light	1
Grey	Gr.	Olive	o.	Light	2
Brown	Br.	Greyish	g.	Medium	3
Yellow	Ye.	Brownish	b.	Dark	4
Red	Rd.	Pinkish	p.	Very dark	5
Orange	Or.	Reddish	r.		
		Yellowish	y.	e.g. bGr5 is Very dark brownish-grey.	

Use + or − for bright or dull.

Self | Speckled | Streaked | Rippled
Waved | Banded | Cloudy | Mottled.

III. Texture.

Sa.	Sb.	La.	Lm.	Lb.	Za.	Zm.	Zb.	C.	P.
5	7	11	21	28	29	30	40	45	8

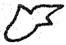
IV. Stones. Chemical nature of and if of P.M. origin.

Stoneless	0	N	Gravel	<¼"	Angular.
Slightly	1	F	C. Gravel	¼–½"	Sub-angular.
Very	2	M	V.S. Stones	½–1"	Rounded.
Oc. Bould.	3	B	S. Stones	1–2"	Shaly.
Rock	4	R	Med. Stones	2–4"	Tabular.
Rock Dom.	5	RD	L. Stones	4–8"	
			Boulders	>8"	

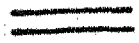
V. STRUCTURE.

 Crumb.

 Nutty.

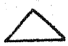
 Cloddy.

 Granular.

 Laminated.

 Prismatic.

 Columnar.

 Pyramidal.

 Structureless.

State size of aggregates.

VI. POROSITY.

Visible
- Porous. Holes 1–3 mm.
- Fissured.
- Spongy. >3 mm.
- Closed.

Handling
- Loose: falls off auger.
- Compact: bites with auger.
- Indurated: auger spins.
- Friable: does not fill auger.
- Tenacious: sucks, fills auger.
- Mellow: bores well. O.M. pres.

VII. ORG. M

Describe in words, nature of. Int. and/or mechanical.

VIII. ROOTS.

Quantity | Size | Health | Age | Shape.

IX. WATER.

o Air dry.
+ Just moist
++ Moist, colour change
+++ Wet, no colour change
++++ Waterlogged

X. SEC. CHEMICALS. } Describe in words.
XI. FAUNA.

XII. CARBONATES.

o nil.
+ $<5\%$.
++ $>5\%$.
+++ $>10\%$.

XIII. pH. as required.

REMINDER (SITE)

1. Date and no.
2. Locality (of pit).
3. Map Ref. 6″ O.S.
4. Series name.
5. Gen. Gp.
6. Elevation in ft. O.D.

   Slope. Abney reading in ° or % with:

   $\left.\begin{array}{l}\text{Concave}\\ \text{Convex}\\ \text{Terraced}\end{array}\right\}$ Uniform *or* irregular.

   Aspect. To nearest 1/16 of compass ($22\frac{1}{2}°$).

   Relief. Macro and micro. Describe.

7. Drainage.

   Profile. Excessive | Free | Imperfect | Impeded.

   S.R. +++ Intense, erosion probable.
   ++ Definite, no erosion.
   + Local run off.

   Site. S. Satis. | α. Seas. Dt. | β. Seas. Wet.
   γ. Perm. Wet | δ. Flood | ε. Springs
   Ir. Irrig. | Wp. Warp. | $\frown$ Easy.
   $\smile$ Difficult.

8. PM, see list.
9. Vegetation. Association | Population | Canopy | Ground vegetation.
10. Mapping data. See Sub. Com. Report. S.S.C.

    Weather conditions, &c.

APPENDIX II

PREPARATION OF SOIL COLOUR CARDS

10 gm. cellulose acetate
300 c.c. acetone
100 c.c. ethyl lactate

Mix the acetone and ethyl lactate and dissolve the cellulose acetate in it; shake before use, otherwise a white film is liable to be formed on drying. The 2 mm. soil sample is rubbed through a 0·2 mm. sieve without grinding. The sieved soil is mixed with some of the cellulose acetate solution on a watch glass with a paint brush and applied to the card. Unless the suspension is well stirred, some sedimentation occurs; paint as quickly and evenly as possible. The suspension should not be too thick or it is liable to crack on drying.

Notes:

Very fine grinding of coarse or fine sandy soils gives a colour which is too light.

Fine grinding of clay soils gives too uniform a coating.

Colour of soil through 0·2 mm. sieve is slightly darker than that obtained by grinding the residue on the sieve.

Colour on card frequently corresponds to that of the ground soil when moist, but is darker than the dry ground soil.

Full and intermediate shades of Ridgeway may be made and standardized.

The matt surface does not reflect light, and approximates to the rough surface of the soil as seen in the field.

The colour is not altered after wetting and drying, neither does it easily rub off. The cards can therefore be treated fairly roughly without loss of usefulness.

The flexibility of the card allows it to be bent to get close to the profile face, &c.

Mottled soils. These are usually described as 'blue-grey

with much orange-yellow mottle'. Each colour could be matched with a separate colour card and a description given as 'The predominant colour is 21″' '″i with mottling of 17″'. When ground the colour is 19″i″. A 'smear' of a mottled soil could be matched to give the 'ground-up' colour. Unless a soil is very much mottled with several colours it should be possible to match, say, two or three predominant colours. The more yellow mottling—the yellower the ground-up soil becomes.

SOME USEFUL BOOKS

The following list of books may be of help to students who find this new soil jargon somewhat difficult to understand.

GENERAL BOOKS ON SOILS

Soils. G. W. Robinson. Murby.
Soil Conditions and Plant Growth. Russel. Longmans.
Principles of Soil Technology. Emerson. Macmillan.
Biological Processes in Tropical Soils. Corbett. Heffer.

SOIL CLASSIFICATION

Elementary:
Evolution and Classification of Soils. Ramann-Whittles. Heffer.
Technical Comm. No. 29. Imperial Bureau of Soil Science. England.

Advanced:
Pedology. Joffe. Rutgers Univ. Press.
Great Soil Groups of the World. Glinka-Marbut. Ann Arbor.

TOPOGRAPHY, GEOLOGY, LAND FORMS

Elementary:
Earth Lore. Shand. Murby.
Scientific Study of Scenery. Marr. Methuen.
Agricultural Geology. Marr. Methuen.
Agricultural Geology. Rastall. Cambridge.

Advanced:
Data of Geochemistry. Clarke. U.S.A. Geological Dept.
Cycle of Weathering. Polynov-Muir. Murby.

Introduction to Stratigraphy. Stamp.
Quaternary Ice Age. Wright.

CLIMATE

Climate and Weather. Dickon. Williams & Norgate.
Climate. Kendrew. Oxford.

VEGETATION AND ORGANIC MATTER

Elementary:
Practical Plant Ecology. Tansley. George Allen.
Aims and Methods in the Study of Vegetation. Tansley and Chipp.
Field Studies in Ecology. Rose Bracher. Arrowsmith.
Plant Ecology. Leach. Methuen.

Advanced:
Plant Ecology. Weaver and Clements. Macgraw Hill.
Plant Sociology. Braun-Blanquet. Macgraw Hill.
The British Islands and their Vegetation. Tansley. Cambridge.
Humus. Waksman. Baillière, Tindall & Cox.
Plant Life Forms. Raunkiaer. Clarendon Press.

MAPPING, FIELD RECONNAISSANCE, ETC.

Popular Map Reading. Laborde.
Manual of Map and Photo Reading and Field Sketching. War Office.
Method of Recording Soil Data. Nikiforoff. Soil Science Soc. of America Proc. 1937.
The Abney Level Handbook. Calkins & Tule. U.S. Forest Service. 1935.
Soil Survey Manual. Kellogg. Misc. Pub. 274. U.S.A. Dept. of Agric. 1937.
Soil Conservation Survey Handbook. Norton. Misc. Pub. 352. U.S.A. Dept. of Agric. 1939.

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